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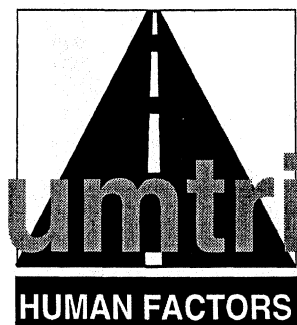
Navigation System Destination Entry:
The Effects of Driver Workload and Input Devices,
And Implications for SAE Recommended Practice.

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HUMAN FACTORS

UMTRI The University of Michigan
Transportation Research Institute

Admin

1. Report No. UMTRI-2000-20	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle Navigation System Destination Entry: The Effects of Driver Workload and Input Devices, and Implications for SAE Recommended Practice	5. Report Date May, 2000
	6. Performing Organization Code account 377218

7. Author(s) Christopher Nowakowski, Yoshihiko Utsui, and Paul Green	8. Performing Organization Report No. UMTRI-2000-20

9. Performing Organization Name and Address The University of Michigan Transportation Research Institute (UMTRI) 2901 Baxter Rd, Ann Arbor, Michigan 48109-2150 USA	10. Work Unit no. (TRAIS)
	11. Contract or Grant No.

12. Sponsoring Agency Name and Address Mitsubishi Electric Corporation Industrial Electronics and Systems Laboratory 1-1, Tsukaguchi-Honmachi 8-Chome Amagaski City, Hyogo 661-8661 Japan	13. Type of Report and Period Covered 9/99 - 5/2000
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Sixteen licensed drivers, 8 younger (20 to 28 years old, mean of 25) and 8 older (55 to 65 years old, mean of 60), entered destinations by (1) entering addresses with the keyboard, (2) selecting them from a list using the keyboard, and (3) selecting them from a list using a remote control. The tasks were performed in a driving simulator both statically and under various driving workloads.

The mean total task times for list selection and address entry, respectively, was 18 and 71 seconds for younger drivers and 32 and 145 seconds for older drivers. Age were the largest factor, with older drivers sometimes taking up to twice as long to complete tasks. Although there was a significant increase (127%) in total task time between static (parked) and dynamic (driving) task times, varying the curve radius (to vary the demand of driving) did not significantly affect destination entry task times. There was, however, a significant driving performance decrement between baseline driving and driving while performing the various navigation tasks for all age groups..

Finally, this study suggested only minor changes to SAE J2365, the associated calculation procedure for SAE J2364. Overall, the measured keystroke times compared well to the estimates in the SAE J2365 calculation procedure, but there was evidence that the age multiplier did not remain constant for repeated keystroke or between input devices. Specifically, the age multiplier was much greater for keyboard use (close to 2) than for remote control use (closer to 1.5).

17. Key Words ITS, human factors, ergonomics, driving, Intelligent Transportation Systems, navigation, destination entry, usability, safety, GOMS, telematics	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161		
19. Security Classify. (of this report) (None)	20. Security Classify. (of this page) (None)	21. No. of pages 69	22. Price

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Navigation System Destination Entry: The Effects of Driver Workload and Input Devices, and Implications for SAE Practice

1 Issues

1. How much practice should be given before testing?
2. How do the measured keystroke times for remote control use compare to the SAE J2365 operator estimates, and what was the effect of input device?
3. What is the effect of age on the keystroke times and total task times?
4. What is the relationship between static (parked) and dynamic (while driving) destination entry task times?
5. How does destination entry affect driving performance?

2 Method

Test Participants

Drivers	Age	
	20-30	55-65
Men	4	4
Women	4	4

Simulator 2-Lane Road Scenario   Hand-Held Remote
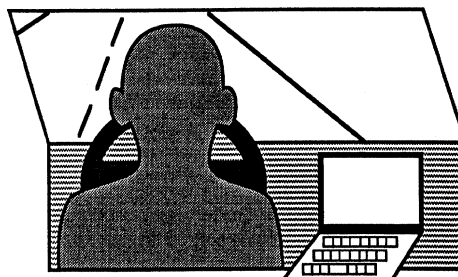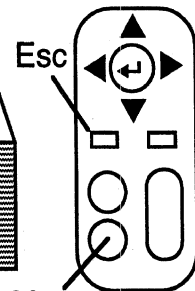
Esc   Menu

Address Entry Task (Static)

Input Device Tested: Keyboard

List Selection Task (Static & Dynamic)

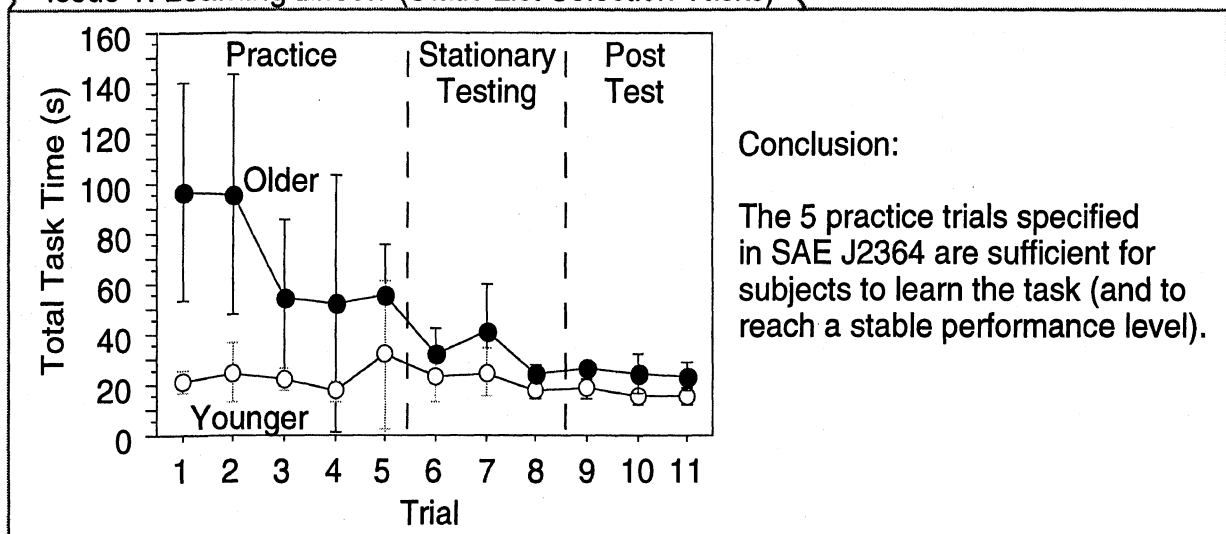Input Devices Tested: Keyboard & Remote

3 Results - Static Task Time

Overview - Mean (and SD) of the Total Task Times (s)

Condition	Static - Parked			Dynamic - While Driving	
Task	Address Entry Keyboard	List Select Keyboard	List Select Remote	List Select Keyboard	List Select Remote
Age 20-30	70.8 (18.2)	17.5 (6.2)	21.7 (8.4)	20.6 (4.7)	23.0 (4.8)
Age 55-65	145.8 (31.3)	36.4 (12.4)	32.5 (13.6)	46.8 (13.1)	37.6 (8.5)

Issue 1: Learning Effects (Static List Selection Tasks)

Conclusion:

The 5 practice trials specified in SAE J2364 are sufficient for subjects to learn the task (and to reach a stable performance level).

Issue 2: Operator Element Comparison

Keystroke Type	Keystroke Times (s)		% Difference
	Experiment	SAE J2365	
Cursor once	0.98	0.80	22.5
Cursor additional	0.43	0.40	7.5
Enter key	0.99	1.20	-17.5

Issue 2: Effects of Input Device on Task Time

Conclusions:

For static test trials, the keyboard was 19% faster than the remote for younger drivers. Under the same conditions, the remote was 11% faster than the keyboard for older drivers.
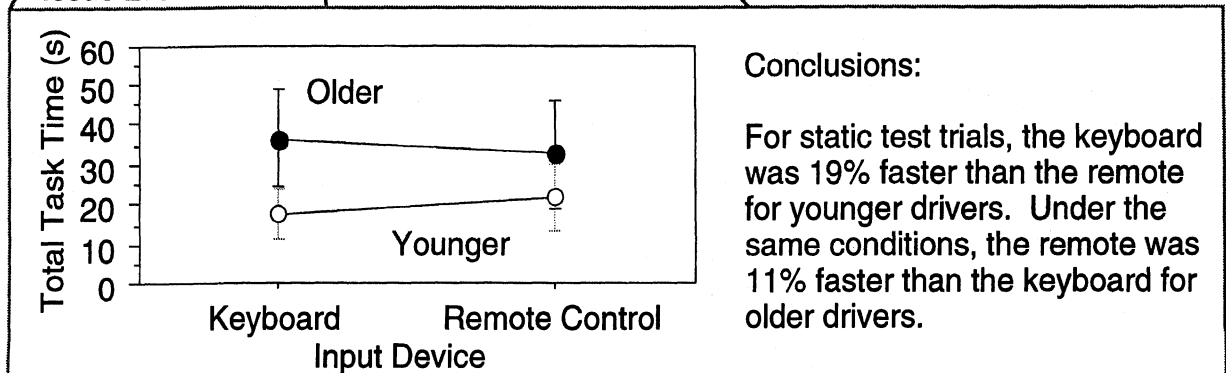
| Calculation Based on	Measured Times (s) Younger	Older	Older to Young Ratio
Cursor once keystroke (remote)	0.98	1.63	1.66
Cursor additional keystroke (remote)	0.43	0.53	1.23
Enter keystroke (remote)	0.99	1.53	1.55
Overall mean keystroke times (remote)	0.80	1.23	1.53
List selection total task time (remote)	21.70	32.50	1.50
List selection total task time (keyboard)	17.50	145.80	2.06
Address entry total task time (keyboard)	70.80	36.40	2.09

4 Results - Dynamic Task Time and Driving Performance

Issue 4: Relation Between Static and Dynamic Task Times
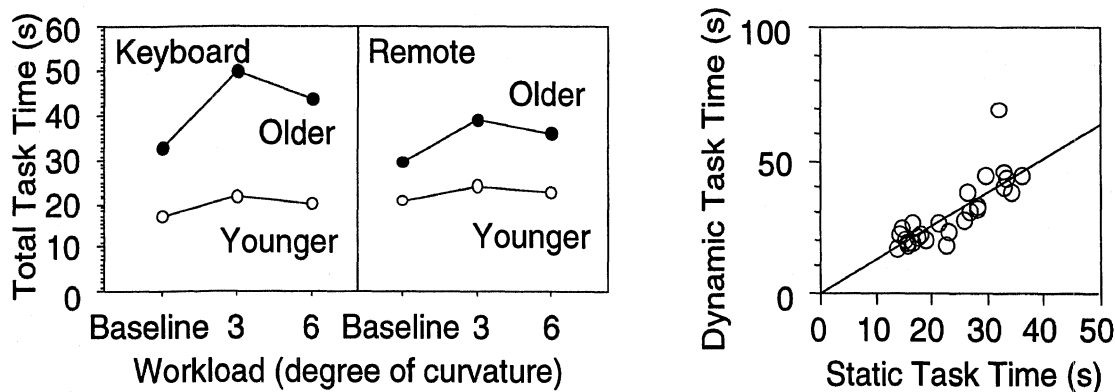
Conclusions: Curvature had no significant affect on the total task times, and dynamic task times were 1.27 times greater than static task times ($r^2 = .95$).

Issue 5: Effects of Destination Entry on Driving Performance
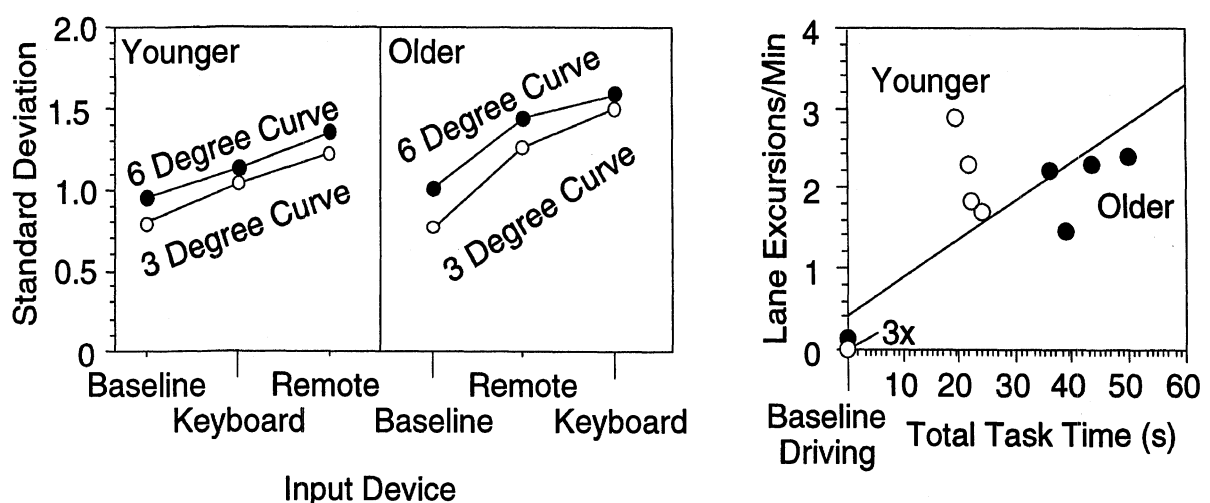
PREFACE

This is the third of 3 evaluations conducted to (1) examine the usability of the Mitsubishi Electric Laptop Car Navigation System, (2) evaluate the impact of driving workload on navigation system task time, (3) evaluate driving performance while engaged in a destination entry task, and (4) check selected assumptions of the SAE J2365 calculation procedure.

The research was conducted while Yoshi Utsui of Mitsubishi Electric Corporation was a visiting engineer at UMTRI. His goals were to (1) provide technical input on navigation system operation and design, (2) assist in the design and analysis of human factors experiments, and (3) generally expand his and Mitsubishi Electric's knowledge of human factors engineering. We would like to thank Mr. Utsui for all of his efforts and for serving as the project liaison with the Mitsubishi Electric Corporation.
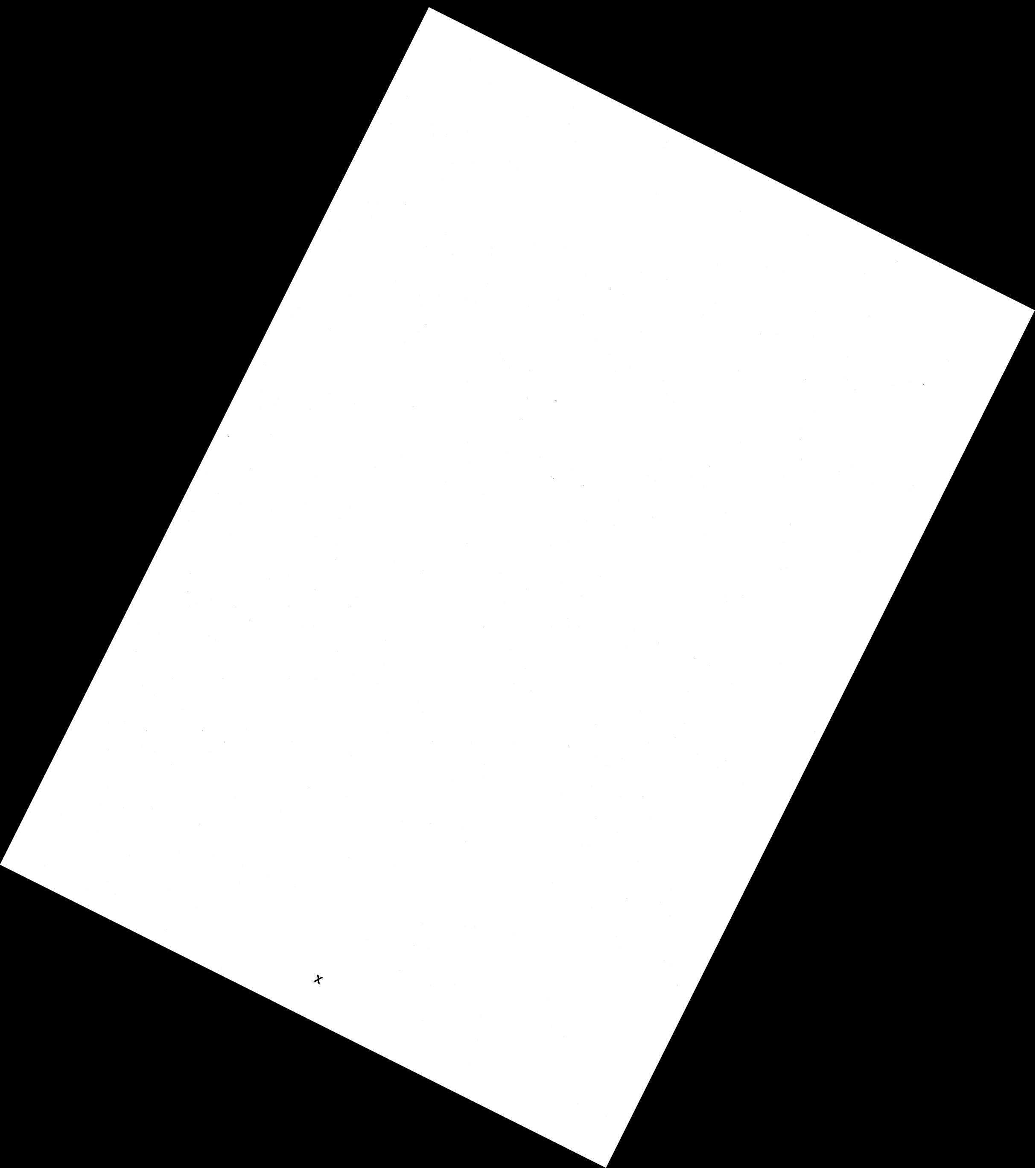
The first 2 evaluations in this project examined the usability of the navigation-system driver interface for Mitsubishi Electric. Due to time constraints of the project, only minor usability enhancements were made during the project. Although there were still known usability issues with the menu system, the address entry dialog, and other parts of the system during the experiment presented in this report, these usability problems were not relevant to the research at hand.

The Mitsubishi laptop navigation system examined in this report was a preliminary version, not the final product. The interface was not expected to be in compliance with SAE Recommended Practice J2364, "15-second rule," as the interface was created before compliance was a design requirement. Therefore, this project should be viewed as an opportunity (1) to use a prototype system to further explore the relationships between task and driving performance and (2) to explore the issues and assumptions surrounding SAE J2364 and J2365 (the calculation procedure for SAE J2364). The authors would like to thank Mitsubishi Electric Corporation for the use of their prototype navigation system during this project and their efforts to instrument their system to permit collection of the data needed for this experiment.

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INTRODUCTION

Concerns About Drivers Using Computers in Moving Vehicles

As new in-vehicle systems are introduced, the nature of driving will certainly change. Systems are being developed for navigation, communications, collision warning and avoidance, adaptive cruise control, and a variety of other purposes. These systems are often implemented independently, with each system having considerable computing power. An alternative and more recent approach is to provide a general purpose computing resource. This may take the form of an automotive specific computer such as the AutoPC, enhanced multipurpose devices (intelligent phones, PDAs, etc.), a laptop computer, or in the future, a wearable computer (Richardson and Green, 2000). The research on the usability of most of these general purpose devices in motor vehicles is quite limited, in part because they were originally intended for office and home use, not for use in a moving vehicle. There are significant differences between the motor vehicle and the office contexts that will influence the optimum choice of controls, displays, and allowable content.

1. While driving, the amount of time a driver can look away from the road is limited, so reading a complex display is a challenge. Furthermore, because glancing to the display is intermittent, time is required to reacquire the information of interest each time the user glances towards the display.

2. The driver has at most only one free hand, so tasks such as two-handed touch-typing are, at best, a challenge to do safely while driving.

3. Drivers not only look at the road, but also need to process information about the road, leaving reduced cognitive or attention resources to process and remember information from in-vehicle systems.

4. Bright sunlight and nighttime driving require a wider range of in-vehicle-display capabilities to assure text will be legible.

5. The physical size of a device can create significant mounting challenges. Device placement often interferes with access to existing vehicle controls and displays.

6. Office devices were not designed to minimize the safety hazards which may be present in the event of an automobile crash.

Of the 6 points listed above, possibly the most important is the first, the concern for driver overload/driver distraction. Overload concerns are quite important when assessing the safety and usability of dedicated systems. In fact, in a study of the relationship between crashes in North Carolina in 1989 and the use of in-vehicle controls and displays, Wierwille (1995) showed that the likelihood of a crash was significantly elevated as the total eyes-off-the-road time increased. According to a regression analysis ($r^2 = .83$), the number of crashes was related to the total eyes-off-the-road time as described by the following equation:

# of crashes = (mean glance time)$^{1.5}$ * (mean # of glances) * (frequency of use)

An extension of Wierwille's model by the author to predict the number of device-induced crashes in the United States for any arbitrary year (Green, 1999a) indicates the number of deaths in the United States associated with destination entry could

reach 21.7 deaths per year by 2007, with the number of injuries being about 100 times that value.

Design Guidelines and Standards

Past Guidelines

Recognizing the safety concerns regarding in-vehicle devices, there have been a number of efforts to provide recommendations and guidelines to improve driver-interface design, especially for navigation systems. (See Green, 1999a for a review.) Design guidelines of particular note include those from (1) the Japan Automobile Manufacturers Association, JAMA (1996), (2) Ito and Miki (1997), (3) the British Standards Institution, BSI (1996), (4) the European HARDIE effort (Ross, Vaughn, Engert, Peters, Burnett, and May, 1995), and (5) two sets of guidelines funded by the U.S. Department of Transportation, one by UMTRI (Green, Levison, Paelke, and Serafin, 1995) and one by Battelle (Campbell, Carney, and Kantowitz, 1997).

SAE J2364 and J2365

The most recent effort to provide design guidelines for in-vehicle navigation systems has been the development of a recommended practice by the Society of Automotive Engineers, SAE J2364 (Green, 1999c). SAE J2364 stipulates that "Any navigation function that is accessible by the driver while a vehicle is in motion shall have a static total task time of less than 15 seconds." The timing starts when the driver moves their hand from the wheel to begin the task and ends when feedback from the last step of the task is received. The vehicle is assumed to be parked during the testing. The 15-second rule represents a compromise given the various views of those voting for the recommended practice, the safety implications from recent research on the use of navigation and other systems, and the boundaries of what is considered acceptable for conventional in-vehicle controls and displays.

A companion to SAE J2364 is the calculation procedure described in SAE J2365 (Green, 1999a,b). SAE J2365 provides a hierarchical method for (1) describing user actions on a step-by-step basis, (2) using look-up tables of estimates for mental operations, visual search, and various keystrokes, and (3) estimating the total task time. The approach was based on the GOMS method (goals, operators, methods, and selection rules) commonly used for evaluating user interfaces to computer systems (Card, Moran, and Newell, 1983).

Although there are other measures for assessing safety and usability, such as the eyes-off-the-road time as described by Wierwille (1995), these methods are generally more costly and time-consuming to measure, requiring a nearly completed design for an assessment. It is well known in human-computer interaction, that even rough estimates of performance early on in the design process can inspire alternative designs. The ability to estimate performance and usability early in the design cycle ultimately leads to more usable products than precisely testing a design once the product is essentially complete.

Assumptions Embedded within SAE J2364 and J2365

The SAE J2364 and J2365 Recommended Practices contain several key assumptions that seem reasonable based on human factors principles. Some of these assumptions have already been verified, but further review is desired to assure the support of the engineering community. Given the current state of knowledge, these practices, as is, represent the best human factors practitioners can do to assure the safety and usability of navigation system in a cost effective manner.

The key assumptions of SAE J2364 are as follows:

1. Driving errors (e.g., lane departures, speed drops) are well correlated with task completion time, as found in all of the studies listed in Table 1.

Table 1. Studies relating to driving errors and task completion time.

Study	Task	Subjects, Age	Roads	Findings
Dingus, Antin, Hulse, and Wierwille (1989)	Dash controls Radio controls Nav system	32, 18-73	Various	Correlation between task time and the number of lane departures.
Nowakowski and Green (1998)	Map reading	16, 18-72	Expressway	Probability of a driving error increased with total task time.
Tijerina (1999)	Nav system Cell phone Radio controls	10, 55 to 65	Test track	Correlation between task time and lane departures.

2. Total eyes-off-the-road time and total task time are well correlated.

As noted earlier, the total eyes-off-the-road time is much more difficult to measure and to predict than total task time. Thus, total task time would be the preferred measure of performance if the two were highly correlated. As shown in Table 2, there exists strong evidence of a high correlation between eyes-off-the-road time and total task time.

Table 2. Eyes-off-the-road time versus total task time.

Study	Task	Subjects, Ages	Roads	Ratio Eyes-Off-Road to Total Task Time
Tijerina, Parmer, and Goodman (1998)	Nav system Cell phone Radio controls	16, 18-70	Test track	0.80
Tsimhomi, Yoo, and Green (1999)	Map Reading	16, 18-70	Simulator	As the task duration increased, so did the number of glances and the total eyes-off-the-road time.
Foley et al. (2000)	Nav system Cell phone CD changer Traffic messages	40, 45-65	Simulator and Expressway	0.80
Wakita and Terashima (1999)	Nav menu	6, 30-60	Test track	0.60

3. Dynamic (on-the-road) task times can be estimated by multiplying the static (parked vehicle) task times by a multiplier proportional to the visual demand of driving.

As shown in Table 3, several studies have examined the relationship between single (static) and dual task (dynamic) performance times. However, there has been little agreement as to how static task times scale up while driving. The dynamic task times were generally found to range from 1.1 to 1.7 times the static task times, but there were also cases (Tsimhomi, Yoo, and Green, 1999) where the dynamic task time was less than the static task time (for short single-glance tasks).

Table 3. Relationship between dynamic and static task times.

Study	Task	Subjects, Ages	Roads	Task Time Ratio Dynamic/Static
Paelke and Green (1993)	Nav system	16, 18-70	Low fidelity Simulator	1.1
Tijerina (1999)	Nav system Cell phone Radio controls	10, 55-65	Test track	1.26
Tsimhomi, Yoo, and Green (1999)	Map reading	16, 18-70	Simulator	1.55
Foley et al. (2000)	Nav system Cell phone CD changer Traffic messages	40, 45-65	Simulator and Expressway	1.7

Several competing theories (Table 4) were evaluated to describe why there is little agreement between studies on how static tasks scale up when they are done while driving. One conclusion drawn from these studies was that people can adopt different strategies and adapt to the tasks in different ways, and these behaviors must be controlled across studies to strengthen between study comparisons.

Table 4. Possible explanations to explain the scale-up differences between studies.

Explanation	Theories	Comments
1. Perceived risk	Single Resource Theory (Kahneman, 1973)	Factors such as perceived risk (on-the-road vs. simulator or high traffic vs. low traffic) could bias the driver's performance to favor driving at the expense of the secondary task.
2. Visual demand	Tsimhomi and Green (1999)	Similarly, increasing the visual demand of driving (through road geometry or traffic conditions) should require that more attention and resources be allocated to driving at the expense of task performance.
3. Driving task	Single Resource Theory (Kahneman, 1973)	The content of the driving task (steering with cruise control vs. steering and speed control) should require that more attention and resources be allocated to the driving task.
4. Secondary task	Multiple Resource Theory (Wickens, 1984)	The task type (audio or listening vs. manual) and task length may affect the scale up from static to dynamic. Also, noted in the data from the Foley et al. (2000) study, the shorter tasks appeared to scale up less than the longer tasks.
5. Age	Numerous studies have reported decreased time-sharing performance in older populations.	Studies which average the scale-up factor across age will likely report lower scale-up factors than studies based solely on older populations.
6. Motivation	Yerkes-Dodson law Speed-accuracy trade off	In some cases, the addition of the time pressure of driving may have caused the dynamic task time to actually decrease, compared to the static task time, though the task time may also have decreased at the expense of accuracy.

4. The operator times (elemental estimates for mental activity, typing letters, typing numbers, etc.) are reasonable. These times were based on the Keystroke-Level Model (Card, Moran, and Newell, 1980) and UMTRI data on the Ali-Scout Navigation System (Steinfeld, Manes, Green, and Hunter, 1996; Manes, Green,

and Hunter, 1998). Additional data for a wider range of interface devices (remotes, true QWERTY keyboards, etc.) are still desired.

5. Task "partitionability" does not affect task completion time. The general belief is that, except in extraordinary circumstances, once driver begins an in-vehicle task, they continue to focus on it until completion, though there may be brief pauses (on the order of 2 seconds or less) for glances to the road. This phenomena has been labeled as "cognitive capture."

Issues

Using a prototype of a navigation system and a driving simulator, there were 5 key issues dealing with SAE J2364 and J2365 that were examined in this study:

1. How much practice should be given before testing?

   According to SAE J2364, 5 practice trials for each task should be given to each subject before testing. The assumption that 5 practice trials will result in a stable estimate of driver performance has not yet been confirmed, though it is generally supported by the literature.

2. How do the measured keystroke times for the remote control compare to the SAE J2365 keystroke operator estimates, and how do total task times vary with input device (keyboard versus remote control)?

   The operator estimates for SAE J2365 were based on the results of several studies in an attempt to create a device-independent, best estimate. This study represents an attempt to verify those estimates and suggest any changes to the estimates if necessary. Unfortunately, only the operator elements for the remote control could be measured in this study.

3. What is the effect of age on operator elements and total task times?

   Although SAE J2364 only specifies the testing of 45 to 65 year olds for compliance with the 15 second rule, SAE J2365, the calculation method, is based on keystrokes for younger drivers and uses an age multiplier to predict task times for older drivers. The age multiplier was computed from a single study and has yet to be verified.

4. What is the relationship between static (parked) and dynamic (while driving) destination entry task times collected in a driving simulator?

   As noted earlier, there has been little agreement between studies as to how the static task times scale up during driving. This study examines the effect of driving workload as a possible factor in the relationship between static and dynamic task times.

5. How does destination entry affect driving performance?

   Since safety is the primary motivation behind the SAE standards, driving performance was recorded and analyzed for tasks that used both input devices and for a variety of workload conditions.

TEST PLAN

Test Participants

Sixteen licensed drivers participated in this experiment, 8 younger (20 to 28 years old, mean of 25) and 8 older (55 to 65 years old, mean of 60). The older group represents the age range specified by SAE Recommended Practice J2364. The younger group represents the expected best performers and were selected for consistency with previous UMTRI studies. Within each age bracket, there were 4 men and 4 women. Participants were recruited via an advertisement in the local newspaper, from the UMTRI subject database, and from friends of the experimenters. All were paid $30 for their participation.

Table 5 summarizes some of the characteristics of the test participants. They reported driving an average of 2,000 to 22,000 miles per year, spanning the average for U.S. drivers (about 10,000 miles per year). All of the test participants passed the Titmus Vision Test (Landolt Rings) for distance vision with a score of 20/40 or better. Three of the younger test participants had participated in a prior usability study involving the same Mitsubishi laptop navigation system, and 1 younger test participant had participated in a prior experiment involving a different navigation system. Although these test participants were more familiar with navigation systems in general (as the prior experiment used the system to guide them to various destinations), their exposure to the destination entry process was minimal.

Table 5. Subject information.

	Younger		Older		Younger	Older
	Female (4)	Male (4)	Female (4)	Male (4)	(8)	(8)
Age	26	24	59	62	25	60
Annual mileage	10,000	13,750	13,000	12,500	11,875	12,750
Paper map use (past 6 months)	2-3	1-2	3-4	4-5	1-2	3-4
Internet map use (past 6 months)	3-4	4-5	1-2	2-3	4-5	1-2
Computer use	Daily	Daily	Weekly	Monthly	Daily	Weekly
Laptop use	Monthly	Monthly	Once in a while	Once in a while	Monthly	Once in a while
Distance vision (corrected)	20/26	20/23	20/23	20/26	20/23	20/25

Test Materials and Equipment

This experiment was conducted using the UMTRI Driver Interface Research Simulator, a low-cost driving simulator based on a network of Macintosh computers (Olson and Green, 1997). The simulator consists of an A-to-B pillar mockup of a car, a projection screen, a torque motor connected to the steering wheel, a sound system (to provide engine, drive train, tire, and wind noise), a sub-bass sound system (to provide vibration), a computer system to project images of an instrument panel, and other hardware. The projection screen, offering a horizontal field of view of 33 degrees and

a vertical field of view of 23 degrees, was 6 m (20 ft) in front of the driver, effectively at optical infinity. Figure 1 provides an overview of the simulator layout.

❶ 1985 Chrysler Laser mockup with simulated hood
❷ 8'X10' projection screen with 3M hi-white encapsulated reflective sheeting
❸ PMI Motion Technologies ServoDisk DC motor (model 00-01602-002 type U16M4) with Copley Controls Corp. controller (model 413) and power supply (model 645)
❹ 3-spoke steering wheel
❺ Sharp color LCD projection system (model XG-E850U) for instrument panel
❻ Sharp computer projection panel (model QA-1650)
❼ 3M overhead projector (model 9550)
❽ Interior Illumination
❾ Audio rack
❿ Sony speaker system (model SR6-48)
⓫ Power Macintosh 9500/200
⓬ Power Macintosh 7100/80AV
⓭ Panasonic low level light camera (model WV-BP550)
⓮ Macintosh Quadra 840AV
⓯ Video rack
⓰ Panasonic VCR (model AG-DS550)
⓱ Panasonic low level light camera (model WV-BP510)
⓲ Power Macintosh 9500/150
⓳ Mitsubishi Amity CN laptop (using Windows 98)
⓴ Sony computer speakers (model SRS-48)

Figure 1. Plan view of UMTRI's Driver Interface Research Simulator.

The destination entry tasks were performed using a Mitsubishi Amity CN laptop (Intel Pentium 166 MMX, 2 GB hard drive, and 64 MB RAM) running the Mitsubishi Car Navigation software (version 1.30RD JA18 US) under Microsoft Windows 98 (Japanese Version). The actual software used was a research prototype. The laptop had an 85-key keyboard (16-mm pitch, 2-mm travel) which was 9.25 inches wide by 6.7 inches deep with an 8.4-inch diagonal LCD screen. The unit was mounted high in front of the center console and angled slightly towards the driver (about 30 degrees), which allowed for an easy reach to the keyboard from the driver's seat. (See Figure 2.)
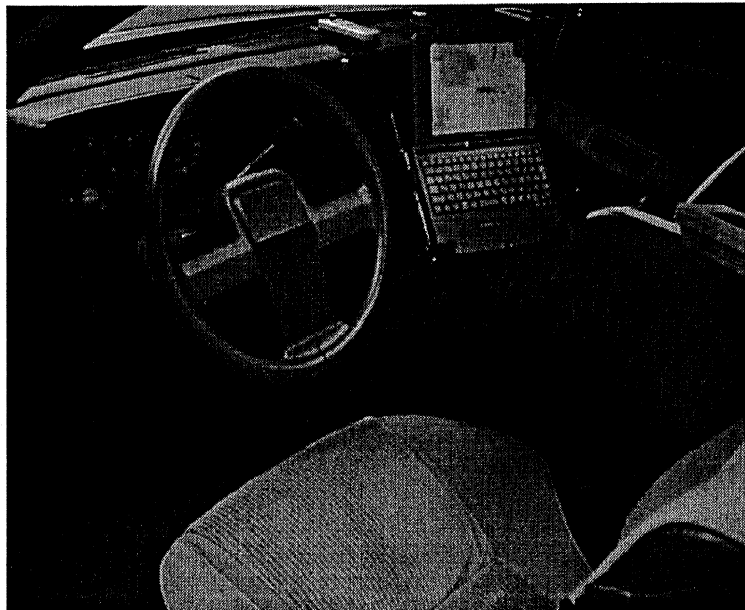

Figure 2. The driver's perspective of the experimental layout.

The laptop could be operated either by using the keyboard short cuts and arrow keys or by using the remote control (Figure 3) provided with the system. The remote measured approximately 5 inches long by 1.5 inches wide with a depth of 1 inch. The round buttons shown were approximately 3/8 of an inch in diameter. The top button functioned as a joystick (operated with the thumb) and was used to mimic cursor keys (e.g., pushing the button to the left was the same as pushing the left cursor key). The remote was kept accessible to the driver by attaching it to the dashboard with Velcro. The trials for a given task were grouped so that the driver did not have to switch between the keyboard and the remote control. During tasks that required the use of the remote control, the driver held on to the remote for the duration of the task.
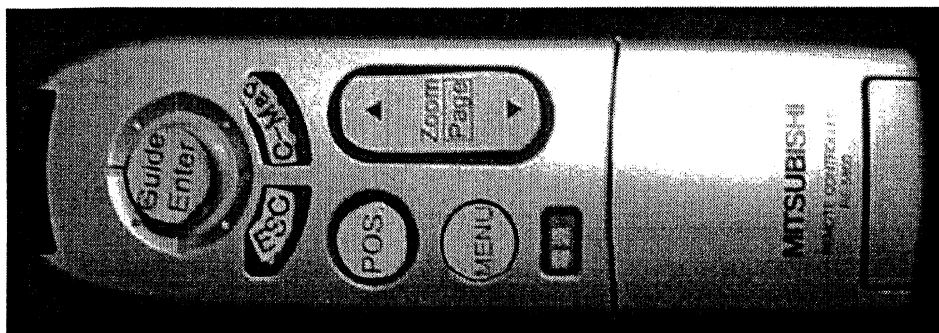

Figure 3. The remote control provided for use with the CarNavigation system.

Destination Entry Tasks

Overview

The navigation system was preconfigured before the experiment to resemble how the system would operate if it was placed in a vehicle, except that the vehicle movement and route guidance were not supported. The vehicle icon was located in a fixed position and the map appeared static even when the driver was driving the simulator. As shown in Figure 4, the program was maximized to full screen and the typical windows menu system and toolbars were hidden. The users were not informed of the menu system's existence, or instructed on how to use the menu to change any of the preset preferences. Additionally, the typical windows mouse pointer was hidden off-screen for the duration of the experiment.
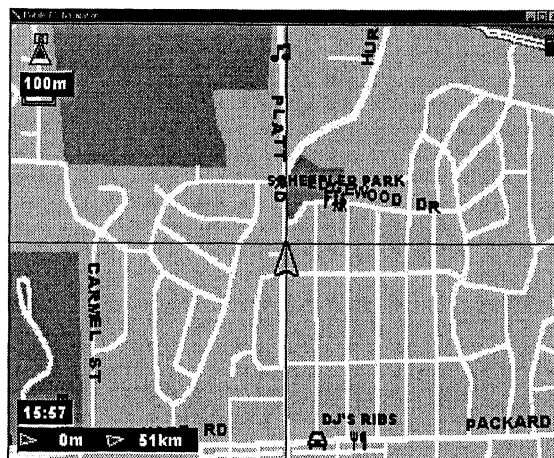

Figure 4. Screenshot of the navigation system at the experiment start.

The test participants were instructed on how to use both the keyboard and the remote control to operate the system. The operation of the interface was quite complex. There were 4 ways to enter a destination using the Car Navigation software; however, only the last 3 listed were used during the experiment since the first method required the use of the mouse pointer.

1. Any location could be right-clicked and set as the destination.
2. An address could be entered, located on the map, and then set as the destination.
3. A location could be stored in the favorites list and later set as the destination.
4. A destination could be selected from the nearby facilities list.

The favorites list was created and used in a similar manner to the favorites or bookmarks used in Internet browsers. A location could be marked as a favorite and stored in a list. When the user selected the favorites list menu option, the list of all locations stored as a favorite appeared. Any item in the list could then be selected, located on the map, and set as the destination.

The nearby facilities list automatically located restaurants, hotels, gas stations, and other facilities within a certain radius from the vehicle. When the user selected the nearby facilities list, a list of facility types was displayed. Within each category, the

nearest facilities to the vehicle's current position were listed by their distance from the vehicle. Any facility on the list could be selected, located and set as the destination.

The Menu System

Pressing the "m" key on the keyboard or pressing the menu key on the remote activated a pop-up menu (Figure 5) in the upper-left quadrant of the screen. When the menu first appeared, no items were highlighted. The up and down arrow keys (or up and down thumb-joystick movements with the remote control) activated the highlight box in the menu and moved the highlight box between menu items. (The first up or down keystroke determined where the highlight box would appear.) The right arrow key (or the enter key) opened the second-level menu for the highlighted menu item. With a second-level menu open, the up and down arrow keys now changed only the highlighted item in the second level (e.g., in Figure 5, with the second-level menu opened, the up and down arrow keys changed the highlight between "Favorites," "Address/Facility," and "Around Vehicle"). The enter key was then used to select the desired menu item, or the left cursor key was used to cancel the second-level menu.
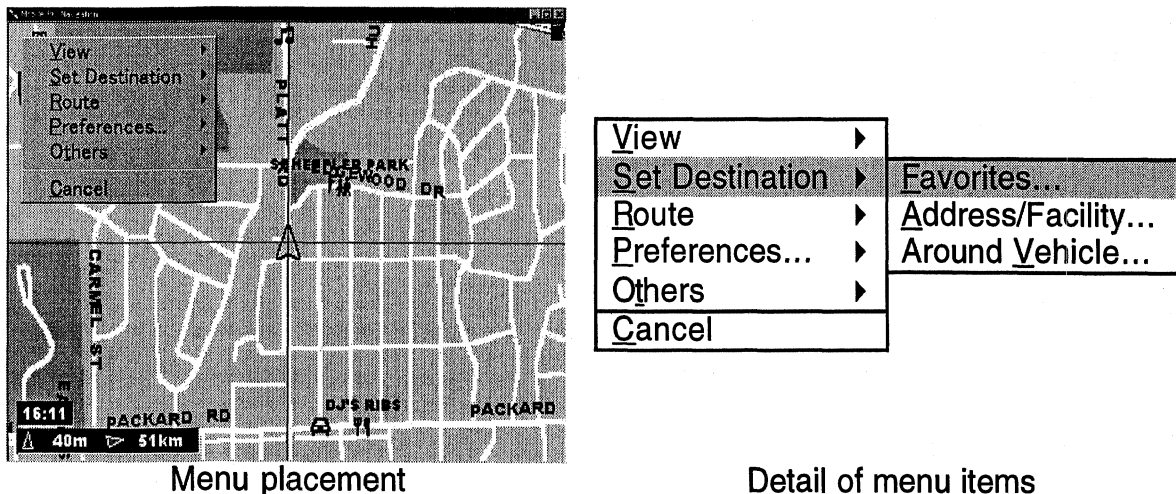
Menu placement   Detail of menu items

Figure 5. Pop-up menu.

All of the items used for this study were found under the "Set Destination" submenu (as pictured above). The address entry dialog box was activated by selecting the "Address/Facility" menu item from the "Set Destination" menu. Similarly, the favorites list was activated by selecting the "Favorites" menu item, and the nearby-facilities dialog box was activated by selecting the "Around Vehicle" menu item.

Address-Entry Task

Selecting the "Address/Facility" menu item from the pop-up menu activated the address-entry dialog box (Figure 6). This dialog box required the user to complete 5 steps to locate an address:

1. Select the country
2. Select the city
3. Specify whether the system should look for a street address or a facility type
4. Select the street name
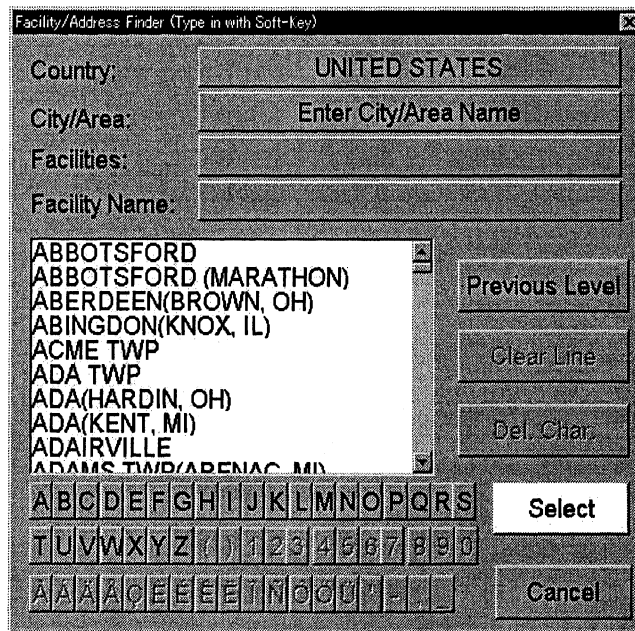5. Select the address range

Figure 6. Address-entry dialog box.

Each step began with the "Select" button in the address-entry dialog box highlighted (refer to Figure 6). The driver was then required to use the arrow keys to cursor down once, which moved the highlighted box from the select button to the first letter in the series of alphabet buttons. The down and right arrow keys then cycled forward through the alphabet while the up and left arrow keys cycled backwards through the alphabet. After the driver had moved the highlight box to the first letter of the country, city, facility type, or street name, the enter key was used to select the highlighted letter.

The system used an intelligent speller to automatically complete the city or street name and to gray-out the letters that were no longer valid (given what had already been typed). As an example, to select the city of Ann Arbor, the driver only needed to select the letters "A," "N," and "N" before the intelligent speller determined that the only city that matched those criteria was Ann Arbor. Letters that were grayed-out were skipped over as the driver used the cursor keys (i.e., grayed-out letters did not require keystrokes as the highlighted box only moved between valid letters when the cursor key was pressed). After the desired city or street name appeared highlighted in the dialog box, the driver was moved the cursor back to the "Select" button and pressed the enter key which began the next step in the address-entry process. The process was repeated for each of the 5 steps listed earlier.

To provide unique test trials of average difficulty, the navigation system database was analyzed to determine the number of characters required, on average, to uniquely identify a location. (See Appendix A.) It was determined that over 50 percent of the cities in the database were selected (using the intelligent speller) after entering only 5 characters. Similarly, for the cities of Chicago, Detroit, and Ann Arbor, over 50 percent of the streets were selected after entering only 4 characters. Combined with the system specific average number of characters required to enter the country, facility type, and address range (Table 6), an address entry of average difficulty was determined to require entry of 13 characters. Note that 13 characters is not the

number of keystrokes required to enter an address, but the number of character selections required. Each character selection entered required several cursor keystrokes to find the desired letter or number and an enter keystroke to select it.

Table 6. Average number of characters required to complete an address entry.

Address Entry Step	Mean Number of Characters Required
1. Select country	1
2. Select city	5
3. Specify facility type	1
4. Select street name	4
5. Select address range	2
Total	13

Favorites and Nearby Facilities Task

The interfaces and dialog boxes for the favorites list and the nearby-facilities list were almost identical. (See Figure 7.) The favorites list presented a list of 6 items at a time. If more than 6 items were in the favorites list, a next button appeared at the bottom right of the list and a previous button appeared at the top right of the list. For keyboard use, both the down and right arrow keys scrolled the highlight box down the list of items. Similarly, both the up and left arrow keys scrolled the highlight box up the list of items. For reference, "Next" was located below the last item shown in the list, and "Previous" was located above the first item in the list. The mapping with the remote control was slightly different than the keyboard as it was more spatially oriented (e.g., down moved to the closest button below the current position and right moved to the closest button right of the current position). In both cases, the enter key selected the highlighted item. Selecting "Next" displayed the next 6 destinations in the list, and selecting "Previous" displayed the previous 6 destinations. A total of 27 items were included in the favorites list for this experiment and all of the favorites-list items were sorted alphabetically to minimize search times.
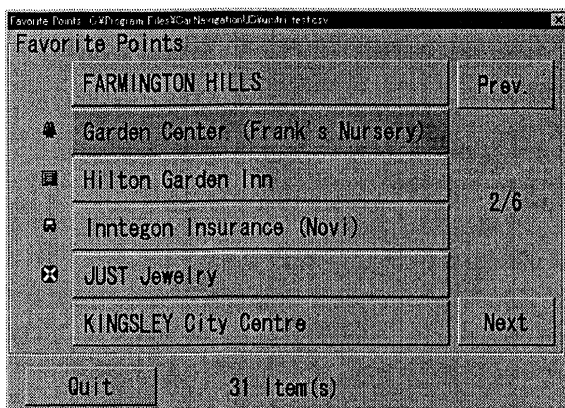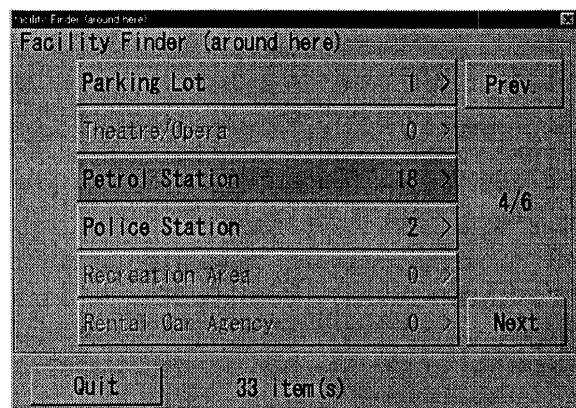
Favorites list   Nearby facilities list

Figure 7. Page 1 of the favorites list and the nearby-facilities list.

The nearby-facilities dialog box used the same interface displaying 6 pages of 6 facility categories each (see Table 7). The cursor movement and "Next" and "Previous" button placement was the same as the favorites dialog box. Categories with no nearby destinations were grayed-out and skipped by cursor key movements. The enter key selected the category and brought up a list of the nearest 6 destinations in that category. If more than 6 nearby destinations for that category were found, the "Next" and "Previous" buttons appeared to allow the user to flip pages. As with the favorites list, the enter key selected the highlighted facility.

Table 7. The 6 screens of nearby-facilities categories.

Airport Amusement Park Bank Bus Station Major Companies City Centre	Historical Monument Hospital Hotel Museum Park & Ride Parking Garage	Rest Area Restaurant Shopping Centre Sports Complex Toll Booth Tourist Attraction
City Hall (no data) Entertainment Ferry Terminal Golf Course University/College	Parking Lot Theatre/Opera Petrol Station Police Station Recreation Area Rental Car Agency	Tourist Information Train Station Volvo Dealer/Workshop

To provide unique test trials of average difficulty, it was experimentally determined that for any vehicle position, the nearby facilities list contained an average of 2 active categories per page (the rest of the categories were grayed-out because there were no nearby facilities in those categories). Since the highlighted box always appears on the first active category (alphabetically), the longest foreseeable task would be to scroll to the fifth page, scroll up to restaurant (the last category which contained multiple pages of entries), scroll through the first two pages of restaurants, and select the first restaurant on the second page. This task required an average of 21 keystrokes for 3 random vehicle positions throughout the metro Detroit area. Given that this was the longest foreseeable task, an average task for this interface was assumed to take half the keystrokes or, in this case, 10 keystrokes.

The only difference between the favorites list and the nearby facilities list was the extra step to select the category in the nearby-facilities list before selecting the final destination. Since the basic interface components, screen designs, button placements, and control movements were used in both the favorites list dialog box and the nearby facilities dialog box, these two interfaces were treated as a single task using an average of 10 keystrokes per trial.

Setting the Destination

After a destination was located using any of the methods listed above, the map was automatically centered over the target location and a location-specific pop-up menu was activated. (See Figure 8.) The location-specific, pop-up menu required the user to cursor up from "Cancel" to "Set Destination" to finish the task of setting a destination.

(Note, there was a way to short cut this last step and cause the highlight to appear directly on "Set Destination" instead of on "Cancel" when the menu first appeared, but this short cut was not revealed to the test participants.)

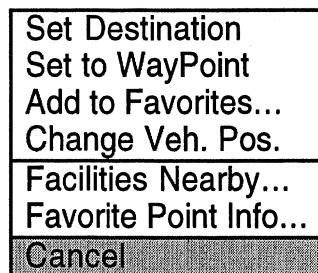| Set Destination |
| --- |
| Set to WayPoint |
| Add to Favorites... |
| Change Veh. Pos. |
| Facilities Nearby... |
| Favorite Point Info... |
| Cancel |

Figure 8. Location-specific, pop-up menu.

Simulated Roads

The driving task was designed to include 2 levels of visual demand/workload. The 2 curve radii were chosen based on Tsimhoni and Green (1999), in which a linear relation was found between the mean visual demand and the reciprocal of curve radius. Specifically, a linear increase in visual demand was found for curves of 3, 6, and 9 degrees of curvature (curve radii of 582 m, 291 m, and 194 m, respectively).

The visual demand was quantified by Tsimhoni and Green (1999) as the ratio of the time spent viewing the road to the time between requests to view the road. The basic protocol allowed drivers to see the road for 0.5 seconds each time they pressed a switch. After 0.5 seconds, the road blanked and the drivers had to activate the switch to see the road again. The visual demand was then calculated by dividing the time spent viewing the road (0.5 seconds) by the time between switch activations.

Tsimhoni and Green (1999) also found the visual demand to be greater at both the beginning and end of the curves, but leveled off to a stable workload within 150 m. As calculated in a later study (Tsimhoni, Yoo, and Green, 1999), the average visual demand found for the stable workload portion of each curve was defined by the following equation (where r is the radius in meters):

Visual demand = 0.252 + 34.5/r

For this study, curves of 3 and 6 degrees of curvature (curve radii of 582 m and 291 m, respectively) were selected. A two-lane test road with 12 ft (3.66 m) lanes was created which contained a total of 4 curves (2 of each curve radii) connected by short straight segments for which data were not collected (see Table 8). Since the test road was used twice (once for testing keyboard operation and once for testing remote control operation), the curve directions were reversed for the second run (i.e., the road started with a 6 degree left turn followed by a 3 degree right turn).

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Table 8. Description of the test road.

Segment Type	Degree of Curvature	Visual Demand*	Curve Direction	Length (m)	Time (min:s)	Number of Secondary Tasks
Start	0			722	0:45	
Curve	3	.31	Right	1198	1:00	1
Straight	0			192	0:10	
Curve	6	.37	Left	1198	1:00	1
Straight	0			292	0:15	
Curve	6	.37	Right	2130	1:45	2
Straight	0			192	0:10	
Curve	3	.31	Left	2130	1:45	2
Finish	0			192	0:10	
Total				8246	7:00	6

*Note: Visual demand was calculated using visual demand = 0.252 + 34.5/r

To keep the workload constant during the secondary tasks, the secondary tasks were not initiated until 200 m after the start of each curve. The curves were also designed to be long enough for a constant visual demand value to be maintained throughout the duration of the secondary task. (Note, for some older test participants, this meant extending each of the curves listed above by 10 to 30 seconds.) This translated to approximately 135 seconds of constant driving workload in the longest curves. In the real world, it would be unlikely to encounter such long, constant-radius curves. Moreover, the sharpest curve, which spanned over 535 degrees, could only be built in a virtual environment.

Test Activities and their Sequence

Overview

The test participants began by completing a consent form (Appendix B) and a biographical form (Appendix C) followed by a vision test. The remainder of the sequence of events is summarized in Table 9. (The entire experiment protocol including the full list of the destinations entered for each practice and task can be found in Appendix D.)

Table 9. Summary of test activities and their sequence.

Activity	Time (min)	Simulator	Input Device	Number of Trials
1. Pre-experiment forms	10			
2. Training on system use	10	Stationary	Both	
3. Practice address entry	10	Stationary	Keyboard	5
4. Practice nearby/favorites list	10	Stationary	Remote	5
5. Address entry testing	5	Stationary	Keyboard	3
6. Nearby/favorites testing	5	Stationary	Remote	3
7. Nearby/favorites testing	5	Stationary	Keyboard	3
8. Break	5			
9. Practice driving	10	Driving		
10. Practice driving and task	10	Driving	Keyboard	6
11. Practice driving and task	10	Driving	Remote	5
12. Nearby/favorites testing	10	Driving	Keyboard	6
13. Nearby/favorites testing	10	Driving	Remote	6
14. Posttest	5	Stationary	Remote	5
Total	120			47

Stationary Practice

The test participants' first introduction to the navigation system was made while the simulator was stationary (stopped at a traffic light). The experimenter explained step by step how to use the navigation system using both the keyboard and the remote control. An example of a favorites list task, a nearby-facilities task, and an address entry task was shown.

In accordance with the requirements of the SAE Recommended Practice J2364, the industry standard method in the U.S. for evaluating the safety and usability of navigation driver interfaces, 5 practice trials were given for address entry (using the keyboard), and 5 practice trials were given with the nearby facilities and favorites list task (using the remote control). The target destinations were read aloud to the test participant; however, a reference index card was also provided for the address entry task.

For the nearby facilities and favorites list task, the destination was read using keywords to prompt the driver to search under the correct list and, in the case of the nearby facilities list, to search under the correct category for the destination. For example, a destination from the favorites list was read as, "Select Cobo Hall Exhibition Center from the favorites list." Each destination from the nearby facilities list also included a category keyword such as the following example: "Select the nearest Sunoco Petrol Station from the nearby facilities list." In this case, "Petrol Station" was the category and "Sunoco" was the destination within that category.

Stationary Testing

After all of the stationary practice trials were completed, 3 blocks of 3 stationary test trials were performed. The first block of 3 test trials involved entering addresses using the keyboard. (See Table 10.) Similar to the practice trials, simulator was parked at a traffic light and the experimenter read the target address to the test participant. An index card with the address was also provided for reference.

Table 10. Address entry stationary test trials using the keyboard.

Trial	Address	Characters Required	Total Keystrokes
1.	33000 Vermont St. Livonia (Wayne, MI)	13	75
2.	53350 Abraham Dr. Macomb (Macomb, MI)	13	60
3.	10 N 7th St. Milwaukee (WI)	13	59
Mean		13	65

The second 2 blocks of stationary test trials involved using the nearby facilities list and the favorites list. The first block of 3 test trials used the remote control, and the second block of 3 test trials used the keyboard. (See Table 11.) Similar to the practice trials, the target destination was read by the experimenter who provided cues about which list contained the target.

Table 11. Nearby facilities/favorites list stationary test trials.

Trial	Input Device	Target Destination	List	Keystrokes
1.	Remote	Novi Expo Center	Favorites	9
2.	Remote	Royal Inn – Livonia	Nearby Hotel	10
3.	Remote	Cobo Conference Center	Favorites	11
4.	Keyboard	Sunoco	Nearby Petrol Station	10
5.	Keyboard	Garden Center (Frank's)	Favorites	10
6.	Keyboard	Wonderland Mall	Nearby Shopping Centre	10

Driving Practice

Three blocks of driving practice were provided for the test participants. The first block of driving used a 6-minute road with random left and right curves varying from 3-degrees of curvature to 9-degrees of curvature. The longest curves were 30 seconds in length and the curves were laid out such that they started with the easier 3-degree curves and ended with the more difficult 9-degree curves. No secondary tasks were performed during the first driving practice. Note that during both the practice and testing, the vehicle speed was set at 45 mph and maintained with the cruise control.

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The second and third blocks of driving practice were provided to ease the test participants into performing secondary in-vehicle tasks while driving. Thus, the difficulty of the task and road combinations was steadily ramped-up from trial to trial during these 2 practice blocks (see Table 12). For both of these practice roads, all of the destinations used had already been used during the static testing blocks. No new tasks or novel destinations were asked of the test participants during the driving practice sessions.

Table 12. Driving practice while operating the navigation system.

Trial	Device	Curve	Target Destination/Task	List
1.	Keyboard	Straight	View "destination"	Menu
2.	Keyboard	Straight	View "current"	Menu
3.	Keyboard	Straight	Open & cancel favorites	Favorites
4.	Keyboard	3 deg right	Sunoco	Nearby Petrol Station
5.	Keyboard	3 deg left	Novi Expo Center	Favorites
6.	Keyboard	3 deg left	Wonderland Mall	Nearby Shopping
-------- Short Break---
1.	Remote	Straight	Open & cancel favorites	Favorites
2.	Remote	6 deg left	Open & cancel nearby	Nearby Facilities
3.	Remote	9 deg right	Cobo Conference Center	Favorites
4.	Remote	9 deg right	Royal Inn – Livonia	Nearby Hotel
5.	Remote	3 deg left	Garden Center (Frank's)	Favorites

Driving Testing

Two 7-minute roads with curves of 3 and 6 degrees of curvature were used to test the navigation system while driving. The first road tested only the keyboard use while the second road tested only the remote control. (See Table 13.) In each case, 3 unique trials (from either the favorites list or the nearby facilities list) for each curve type and device combination were created. Each trial required 10 keystrokes from within the favorites or nearby facilities dialog box to find the destination.

Table 13. Nearby facilities/favorites list test trials while driving.

Trial	Device	Curve	Target Destination	List
1.	Keyboard	3 deg right	Best Western	Nearby Hotel
2.	Keyboard	6 deg left	Motorola Automotive	Favorites
3.	Keyboard	6 deg right	Standard Federal	Nearby Bank
4.	Keyboard	6 deg right	Quantum Controls	Favorites
5.	Keyboard	3 deg left	Maggies's Coffee House	Nearby Restaurant
6.	Keyboard	3 deg left	Just Jewelry	Favorites
-------- Short Break---
1.	Remote	6 deg left	Detroit Receiving Hospital	Nearby Hospital
2.	Remote	3 deg right	Mobil	Nearby Petrol Station
3.	Remote	3 deg left	Lilley Park	Favorites
4.	Remote	3 deg left	Cadillac-Farmer Parking	Nearby Parking Lot
5.	Remote	6 deg right	Arborland Mall	Favorites
6.	Remote	6 deg right	Orchard Lake Deli and Ribs	Favorites

Posttest

After the driving portion of the study was completed, a final block of 5 posttest trials from the favorites and nearby-facilities list was administered. During the posttest the simulator was stationary (stopped at a traffic light), and only the remote control was used.

RESULTS

Overview

Although 16 drivers were tested, most of the analyses were based on 13 test participants since 2 older women and 1 older man were unable to complete the entire experiment. Two older women were unable to complete any of the tasks on their own after over 2 hours of instruction. The remaining test participant who did not complete the experiment was an older man who completed all of the stationary trials successfully, but was unable to complete any of the tasks while driving. He reported that the task was so difficult that he would never even conceive of trying to do it while driving.

There were 2 common problems encountered by the older test participants, which contributed to the difficulty of the experiment.

1. Both the keyboard and the remote control were too sensitive, resulting in numerous unintended key presses and actions that required correction.

2. The complexity of the task sequence itself was difficult to learn. Some drivers were unable to remember the steps after repeated guided practices.

The input device sensitivity problem occurred most often for older test participants. Often an intended single keystroke registered as 2 or 3 keystrokes, which greatly hindered both the learning and use of the system. The difficulties in using the entry devices often exacerbated the difficulty in learning and remembering the complex sequence of steps required to enter an address. As an example, when trying to select a menu item, the user would cursor up 4 times, but the system would register 5. To correct, the participant would cursor down once which would register 3 times. If the instability caused by the overcorrections continued for several seconds, the user forgot where they were in the sequence of events, which caused even more delays and hindered their ability to learn the task.

The analyses of the results that follow are organized into 3 major sections:

1. The total-task completion time for each of the stationary tasks.
2. The keystroke times for stationary tasks that used the remote.
3. The effects of workload on both task and driving performance.

Analysis of Stationary Tasks

Overview

Three distinct tasks were performed while the vehicle was stationary: (1) address entry using the keyboard, (2) favorites- and nearby-facilities-list item selection using the keyboard, and (3) favorites- and nearby-facilities-list item selection using the remote control. The total-task completion times for the stationary tasks (Table 14) were based on 14 test participants (2 of the older women were unable to complete this task as noted earlier). Notice that in all cases, entry times exceeded the limits specified in SAE J2364 by a factor of more than 2 for the test population.

Table 14. Summary of the destination entry total task times and standard deviations.

Age	Keyboard Address Entry	Keyboard List Selection	Remote Control List Selection
Younger	70.8 (18.2)	17.5 (6.2)	21.7 (8.4)
Older	145.8 (31.3)	36.4 (12.4)	32.5 (13.6)

Note: Entries are in seconds

Address-Entry Task

The first task performed by the test participants was the address-entry task. In this task 3 addresses were entered using the keyboard's arrow keys while the vehicle was stationary. Each address required an average of 65 separate keystrokes to complete the task. The total task time ranged from 39.2 to 206.7 seconds with a mean of 101.8 seconds (SD = 44.5).

Driver age had the largest effect on the mean total-task completion time. As shown in Figure 9, older drivers took 75 seconds longer (107 percent more time) than younger drivers. Additionally, the variability of the task-completion time was much greater for older drivers with the standard deviation increasing from 18.2 to 31.3 seconds (72 percent) with age.
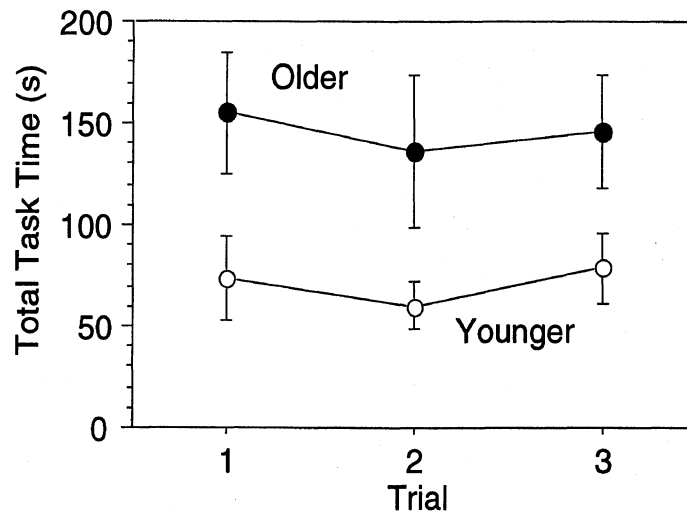

Figure 9. Effects of age on address entry (error bars denote +/- 1 SD).

Favorites and Nearby-Facilities List Task

The second set of tasks performed by the test participants was the favorites- and nearby-facilities-list tasks. In these tasks, 3 destinations contained in either the favorites list or the nearby-facilities list were selected using either the keyboard or the remote control while the vehicle was stationary. Each destination required an average of 10 separate keystrokes within the dialog box to complete the task. The total task time ranged from 10.9 to 72.6 seconds with a mean of 25.7 seconds (SD = 12.5).

Similar to the address-entry task, the largest effect was that of age, which increased the mean-total-task-completion time by 15 seconds (79 percent). The variability of the task-completion time also increased with age from 7.6 seconds for younger drivers to 12.9 seconds for older drivers (a 70 percent increase). The effects of the input device were less clear (Figure 10). For the younger drivers, the keyboard was slightly faster with a mean task-completion time of 17.5 seconds compared to 21.7 seconds for the remote control (a 19 percent decrease in task time). For the older drivers, the remote control was slightly faster with a mean-task-completion time of 32.5 seconds compared to 36.4 seconds for the keyboard (an 11 percent decrease in task time).
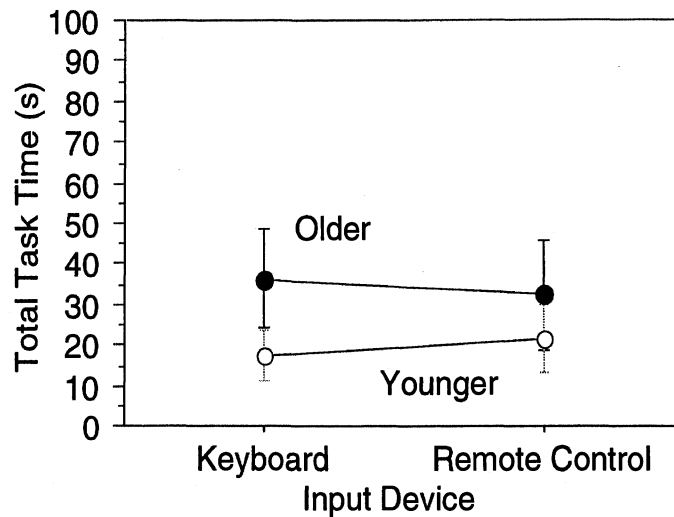

Figure 10. Effects of age and input device on address selection.

Learning Effects

The SAE Recommended Practice J2364 specifies that the test participants perform 5 practice trials followed by 3 test trials. Figure 11 suggests that the protocol of 5 practice trials was sufficient to guarantee that the test trials were measured at a stable level of novice performance. However, it should be noted again that for 1 out of 4 of the older test participants, 5 practice trials was not enough to guarantee even minimal performance as they were unable to complete either the address entry or the favorites and nearby-facilities tasks.

It should also be noted that there was still a large performance difference between novices and experts. Experts with the system averaged 43 seconds per address when tested under similar circumstances. When comparing the experts to the younger drivers in the experiment (who averaged 70.8 seconds per address), the younger drivers took 27.8 seconds (64 percent) longer than the experts did.
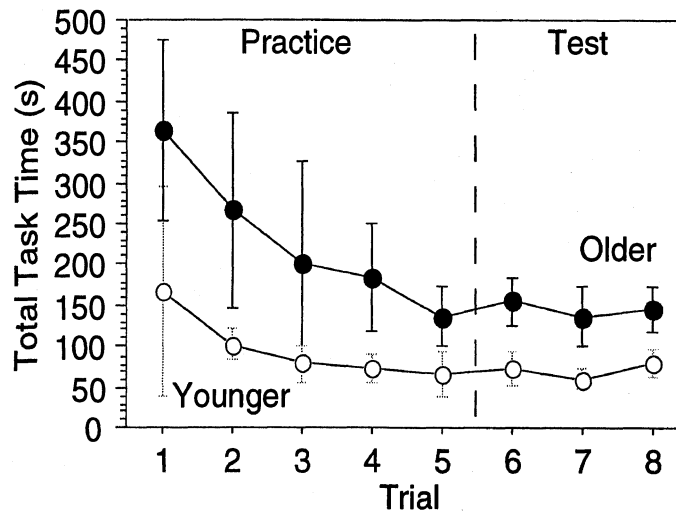
Figure 11. Effects of practice on address entry.

The same trend held true for shorter tasks such as the favorites- and nearby-facilities-list item selection, which averaged only 25 seconds to complete (see Figure 12). A repeated-measures ANOVA was used to formally verify the practice assumptions. The practice, stationary test, and posttest blocks were compared as a within-subject factor and age was coded as a between-subject factor. Age, $F(1,11) = 33.8$, $p < .05$; block, $F(2,22) = 27.4$, $p < .05$; and the age by block interaction, $F(2,22) = 14.2$, $p < .05$, were all significant.
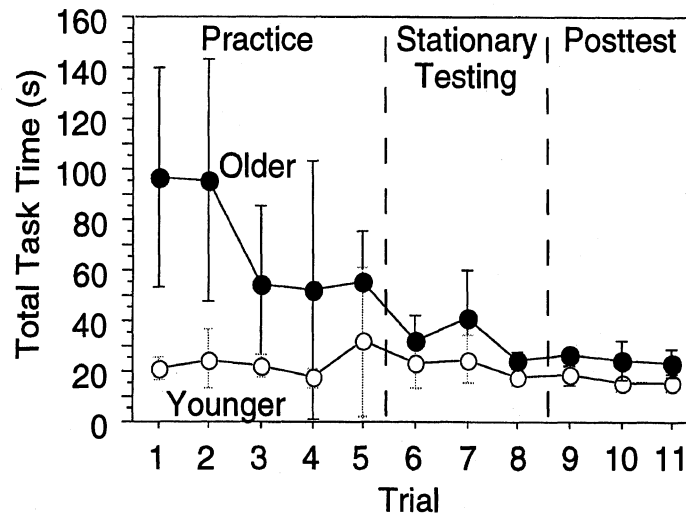

Figure 12. Effects of practice on favorites and nearby-facilities list-item selection.

The interaction between age and block merely indicated that the practice was more beneficial for the older test participants as is clearly shown in the graph above. A Tukey-Kramer post hoc test further verified that only the difference between the practice block and the test or post-test block was significant. No significant difference was found between the test block and the posttest block even though there was mean response time decrease of 3.8 seconds between the stationary testing block (relatively

near the beginning of the experiment) and the posttest block (at the end of the experiment).

Similar to the address-entry task, when experts were tested with the same tasks, they averaged 9.8 seconds per address. The younger novice drivers in this experiment averaged 13.7 seconds (140 percent) longer than the experts did. As demonstrated by this task, the large difference between the novice and expert performance could easily result in the difference between a feature passing or failing the 15-second rule.

Analysis of Keystrokes for the Remote Control

Overview

Individual keystroke times were collected for the tasks that used the remote control as the input device. To minimize the impact of mental operations, screen searches, and computer response times, the first keystroke of any sequence using the remote control use was disregarded. The resulting 6,284 cursor keystrokes and 1,619 enter or cancel keystrokes were analyzed for 14 test participants and compared to the keystroke time estimates described in SAE J2365. (See Table 15.)

Table 15. Summary of keystroke times and comparison to SAE J2365 estimates.

	Experiment Findings (Remote)		J2356 Estimate (Keystrokes)	
	Younger (s)	Older (s)	Younger (s)	Older (s)
Cursor Once	0.98	1.63	0.80	1.44
Cursor Additional	0.43	0.53	0.40	0.72
Enter Key	0.99	1.54	1.20	2.16

Cursor Keystrokes

Cursor keystrokes were separated into two types: (1) first cursor keystroke and (2) successive cursor keystrokes. A successive keystroke was defined as the second or greater occurrence of a single key. Thus, if the down arrow key was depressed 3 times in a row, the first keystroke was analyzed in the category of first cursor keystrokes and the remaining 2 keystrokes were analyzed as successive cursor keystrokes.

Figure 13 shows the distribution of first cursor keystrokes split by driver age. The mean keystroke time for younger drivers was 0.98 seconds (SD = 0.94 s) while the mean keystroke time for older drivers was 1.63 seconds (SD = 1.65 s) representing a 66 percent increase due to age. The distribution's median was 0.73 seconds for younger drivers and at 1.11 seconds for older drivers. Alternatively, the SAE J2365 calculation method estimated 0.80 seconds for younger drivers and 1.44 seconds for older drivers. Based on the mean keystroke times, SAE J2365 underestimated the cursor keystroke times by 18 percent for younger drivers and 12 percent for older drivers.
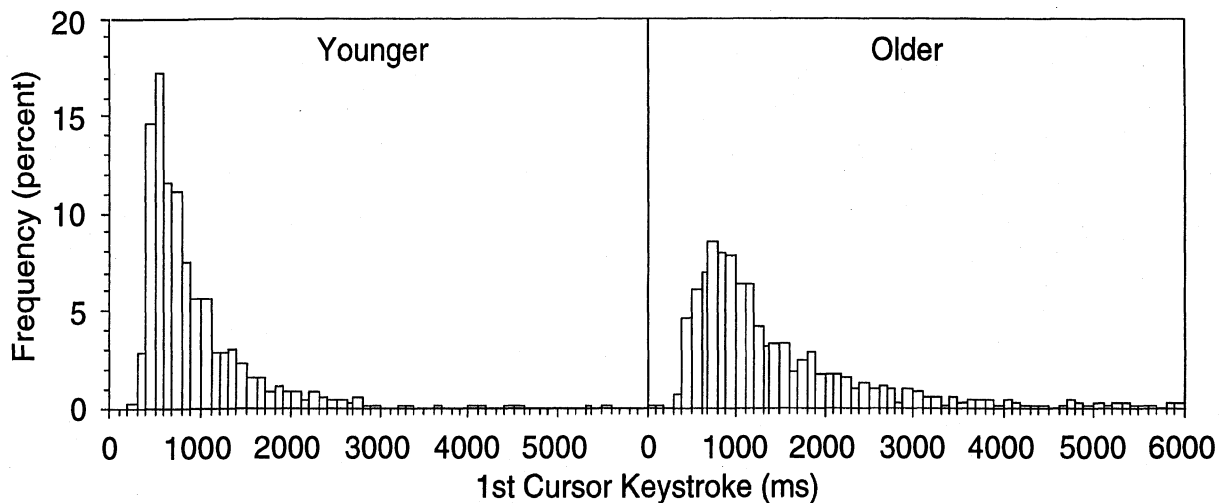
Figure 13. Distribution of keystroke times for the remote control's cursor keys.

Successive keystrokes were made much faster than the first keystroke (Figure 14). The mean successive keystroke time for younger drivers was 0.43 seconds (SD = 0.63 s) while the mean successive keystroke time for older drivers was 0.53 seconds (SD = 0.78 s) representing only a 23 percent increase due to age. The distribution's median occurred at 0.30 seconds for younger drivers and at 0.34 seconds for older drivers. Alternatively, SAE J2365 estimated 0.40 and 0.72 seconds for younger and older drivers, respectively. The experimental findings showed that SAE J2365 underestimated the keystroke times by 7 percent for younger drivers and overestimated the keystroke times by 35 percent for older drivers.
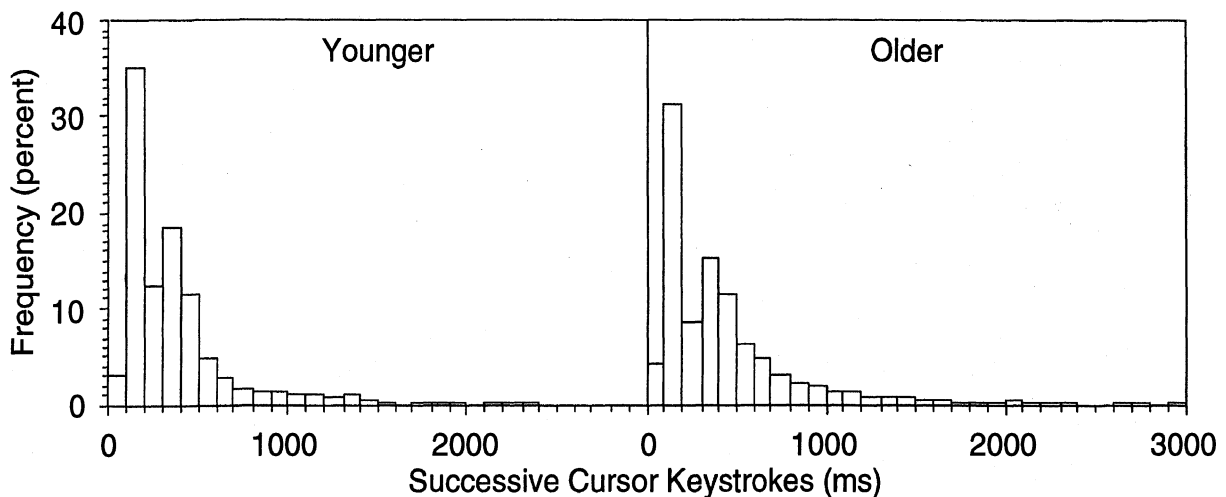

Figure 14. Distribution of successive remote control cursor keystrokes.

Enter and Cancel Keystrokes

Enter and cancel keystrokes were combined into a single category since there were only a few cancel keystrokes encountered during the trials. There were no successive enter or cancel keystrokes. Overall, these keystrokes were comparable in duration to first cursor keystrokes. As shown in Figure 15, the mean enter keystroke time for younger drivers was 0.99 seconds (SD = 1.01 s) while the mean enter keystroke

time for older drivers was 1.54 seconds (SD = 1.53 s) representing a 55 percent increase due to age. The distribution's median occurred at 0.73 seconds for younger drivers and at 1.09 seconds for older drivers. Alternatively, SAE J2365 estimated 1.2 and 2.16 seconds for younger and older drivers, respectively. This represented a 21 percent overestimate for younger drivers and a 40 percent overestimate for older drivers.
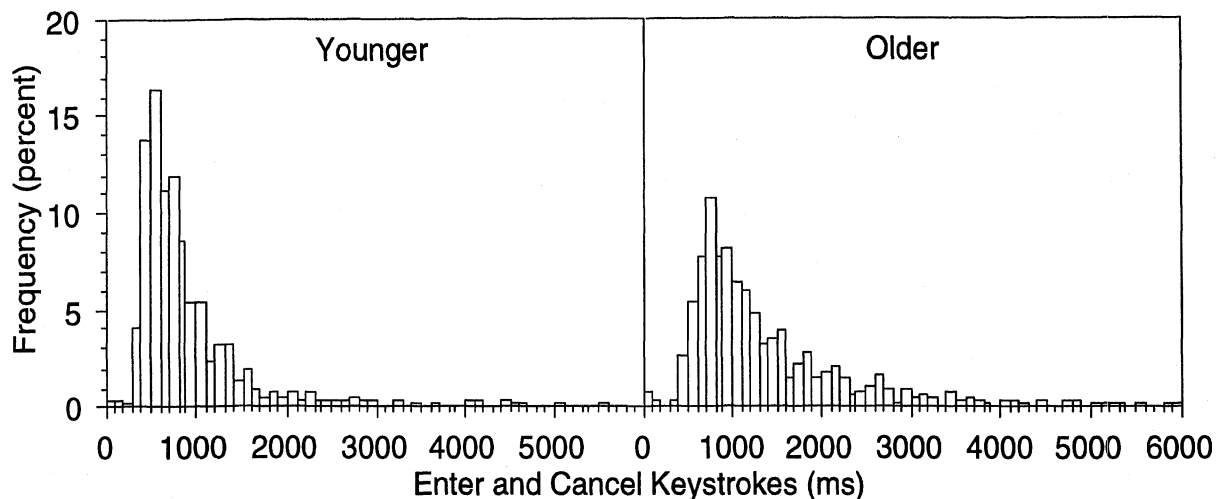

Figure 15. Distribution of single enter-or-cancel keystrokes using the remote control.

Analysis of Workload and Driving Performance

Total Task Time

The total-task-time analysis examined 3 levels of workload: (1) stationary, (2) driving in gentle curves (3 degrees of curvature), and (3) driving in sharper curves (6 degrees of curvature). The task performed by the drivers involved selecting a destination from the favorites list or from the nearby-facilities list using either the keyboard or the remote control. The analysis was based on only 13 subjects since 2 of the older women and 1 older man were unable to complete the task. The total task times ranged from 13.8 to 81.9 seconds with a mean of 28.6 seconds (SD = 13.3).

The following 3 factors were examined using a repeated measures ANOVA:

1. Age
2. Device (keyboard vs. remote control)
3. Workload (static, 3 degrees of curvature, and 6 degrees of curvature)

A significant main effect was found for age, $F(1,11) = 45.7$, $p < .05$, and workload, $F(2,22) = 10.7$, $p < .05$. Similar to the address entry task, age increased the total task time by a factor of 2 with younger drivers averaging 20.8 seconds and older drivers averaging 40.3 seconds to finish each task. As shown in Figure 16, a mean total-task-time increase of 4.5 seconds (17 percent) was found between performing the task while stationary and performing the task while driving in a gentle curve. However, an unexpected finding was that the total task time decreased by an average of 3 seconds as the workload increased from driving in a gentle curve to driving in a sharper curve.

A Tukey-Kramer post hoc test verified that significant differences existed between the baseline and driving conditions, but the post hoc test did not find the 3-second total task time difference between driving in gentle curves and driving in sharper curves to be significant.
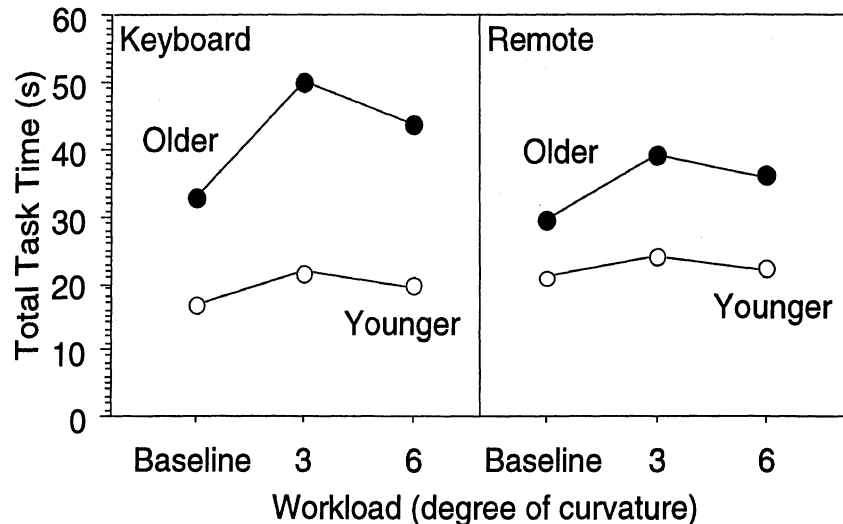

Figure 16. Effects of age, device, and workload on total task time.

Although device was only marginally significant, $F(1,11) = 3.17$, $p = .10$, the device by age interaction was significant, $F(1,11) = 18.9$, $p < .05$. This interaction indicated that the use of the remote control benefited the older drivers more than the younger drivers. In fact, for younger drivers, the keyboard was 3.1 seconds faster (14 percent) than the remote control, but for older drivers, the reverse was true since the remote control was 5.1 seconds faster (12 percent) than the keyboard.

Driving Performance

Two measures of driving performance were examined: (1) standard deviation of lane position and (2) the number of lane excursions. The standard deviation of lane position was calculated with a sample rate of 30 Hz for each 40 second (55 second for older drivers) stretch of roadway where a trial was given even if the trial itself was completed in less time. Thus, the values reported underestimate the impact of a secondary task on driving performance.

Lane excursions were defined as a condition where the vehicle crossed a lane line for a duration of 0.25 second or more. Although this definition may be less strict than most studies, it was required to rule out line crossing due to the randomness of the vehicle position when travelling near a lane line. The rationale for the .25 second requirement was simply that it would take a driver at least 0.25 seconds to notice and respond to a lane excursion. Similarly, repeated crossings of a lane line during a given duration were only counted as 1 lane excursion. For example, if the car was on the centerline for 5 seconds and crossed the centerline 12 times in those 5 seconds, it was only counted as a single lane excursion. However, multiple lane excursions in a single trial were recorded if the driver clearly recovered from a lane excursion and returned to driving completely within the lane for several seconds.

Overall, there was a correlation between total task time and the driving performance measures. As shown in Figure 17, as the task time (averaged across trials) increased, the driving performance decreased (characterized by an increase in average standard deviation of lane position across trials and the total number of lane excursions totaled). (Each point represents the 3-trial total number of lane excursions for the 3-trial-mean task-time for each test participant.) Total task time alone, however, explained 10 percent or less of the variance in driving performance.

SD = .952 + .011 * TTT   R^2 = .105   LE = .637 + .086 * TTT   R^2 = .091
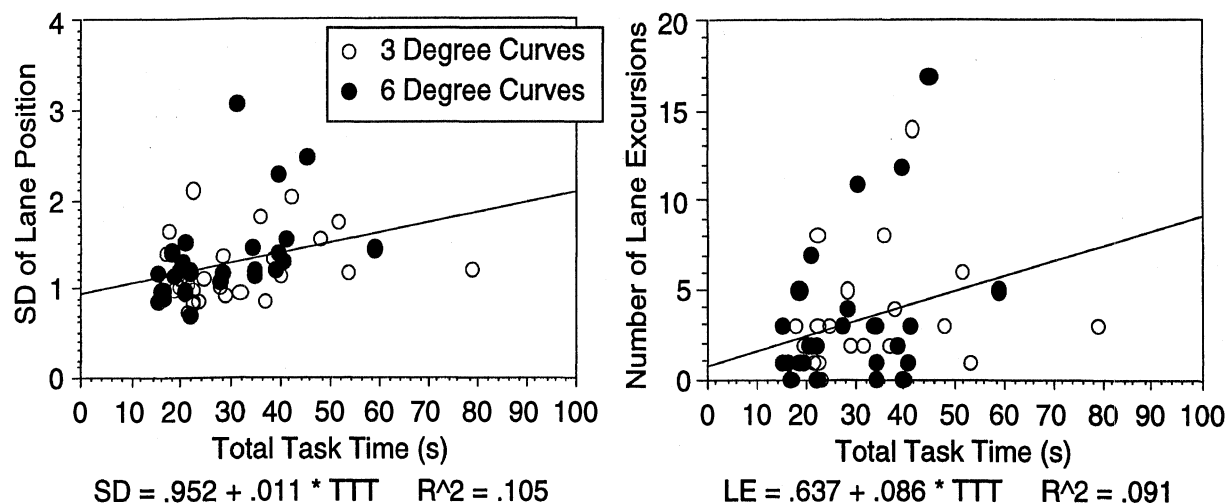
Figure 17. The relationship between total task time and driving performance.

Both measures of driving performance were further evaluated using a repeated measures ANOVA with the following 3 factors:

1. Age
2. Curve (3 or 6 degrees of curvature)
3. Device (baseline or no device, remote control, or keyboard)

For the standard deviation of lane position, the data indicated that both curve, $F(1,11) = 4.8$, $p < .05$, and device, $F(2,11) = 9.3$, $p < .05$, were significant. Age was not significant. As shown in Figure 18, the largest effect seen was the difference between the baseline driving condition (where the drivers were not performing a secondary task) and the task conditions. A 0.31-foot (35 percent) increase in lane variance was seen between the baseline driving condition and the tasks performed using the remote control. Similarly, a 0.51-foot (58 percent) increase in lane variance was seen between the baseline driving condition and the tasks performed using the keyboard. A Tukey-Kramer post hoc test verified that both of these differences were significant; however, the 0.20-foot (15 percent) increase in lane variance between driving with the remote control and driving using the keyboard was not significant. The effect of road curvature was slightly less, though still significant, showing a .16-foot (15 percent) increase in lane variance as the curvature increased from 3 to 6 degrees.
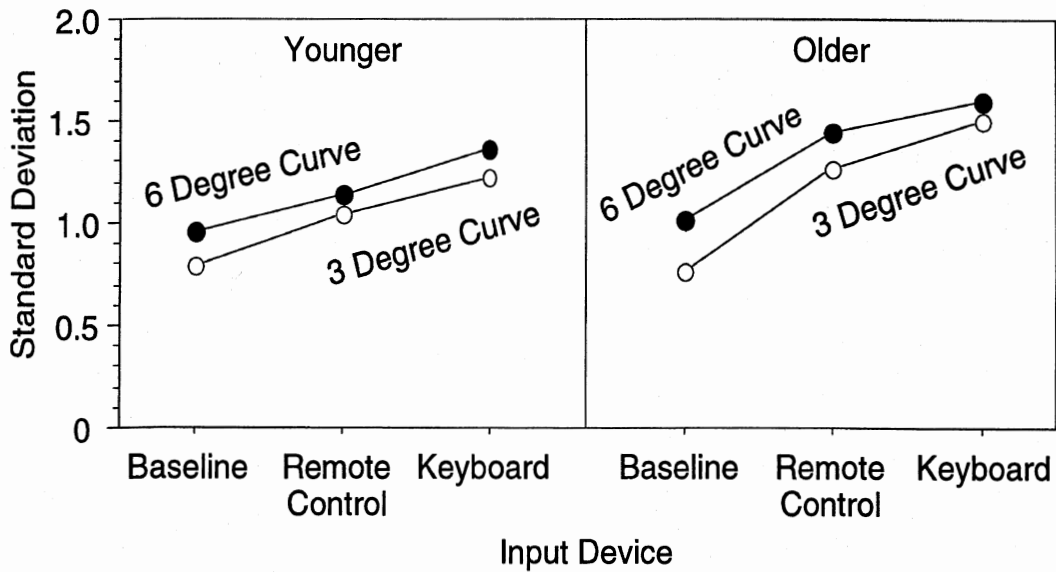
Figure 18. Effects of age, curve, and device on the standard deviation of lane position.

For lane excursions, the data indicated again that only device, F(2,22) = 9.5, p < .05, was significant. This result was expected given that the baseline condition contained almost no lane excursions. As shown in Figure 19, the addition of the navigation task using the keyboard as an input device while driving produced a mean of 3.8 lane excursions over 6 trials, while tasks using the remote control produced a mean of only 2.6 lane excursions over 6 trials. A Tukey-Kramer post hoc test confirmed that driving while using either the remote control or the keyboard was significantly worse than the baseline driving condition, but the apparent performance improvements seen while using the remote control compared to the keyboard were not statistically significant.
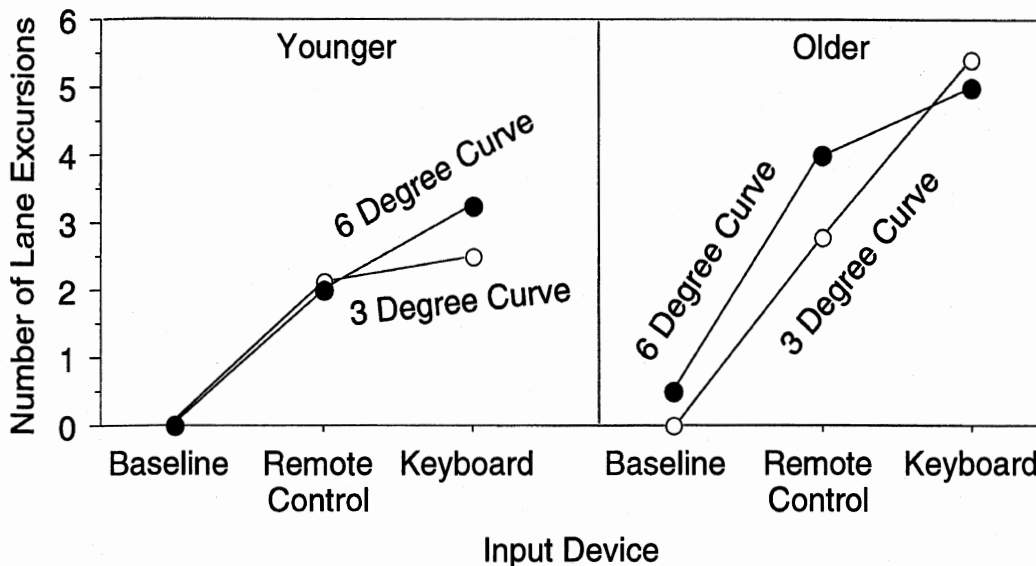
Figure 19. Effects of age, curve, and device on lane excursions.

There was a slight, though not statistically significant effect seen for the curvature. The mean number of lane excursions on 3 degree curves was 1.95 while the mean number of lane excursions on 6 degree curves was 2.25 (an 18 percent increase). Given that curvature was a significant factor for lane variance, it was also expected to appear significant in the lane excursion analysis.

DISCUSSION

How did the keystroke times (for the remote) compare to the SAE J2365 estimates?

As described in Green (1999b), the SAE J2365 Recommended Practice for calculating the time to complete in-vehicle navigation and route guidance tasks developed keystroke estimates based primarily on the work of Card, Moran, and Newell (1980 and 1983) and on Manes, Green, and Hunter (1998). Card, Moran, and Newell developed the initial keystroke-level model based on typing with a full QWERTY keyboard. Manes, Green, and Hunter examined the distributions of keystrokes using the Siemens Ali-Scout Navigation System.

The SAE J2365 keystroke estimates are based on two components:

1. A keystroke-time estimate for a younger driver.
2. An age multiplier (approximately 1.8 for drivers aged 55 to 65).

The first component of SAE J2365 is the keystroke-time estimate for younger drivers. The keystroke-times for younger drivers (using the remote control) found in this study compared reasonably well to the keystroke-time estimates for younger drivers proposed in SAE J2365. (See Table 16.) Some differences were expected given that the SAE J2365 keystrokes estimates were supposed to be universal and not specific to any particular device, and the context and design of the device were expected to influence the keystroke times. For example, the original work done by Manes, Green, and Hunter (1998) found first cursor keystrokes to average 1.71 seconds and enter keystrokes to average 1.55 seconds, but these times were adjusted in SAE J2365 due to the fact that the Ali-Scout used very small buttons (less than 1 cm^2).

Table 16. Comparison of keystroke estimates for younger drivers.

Key Category	Keystroke Times		% Difference
	Experiment	SAE J2365	
Cursor Once	0.98	0.80	22.5
Cursor Additional	0.43	0.40	7.5
Enter Key	0.99	1.20	17.5
Overall Mean Keystroke Time	0.80	.80	0.0

In the case of this current study, a remote control was used as the input device. The remote used a thumb joystick which functioned as all 4 cursor keys and as the enter key. This configuration might explain why no difference existed between the first cursor key and the enter key even though the SAE J2365 estimate predicts a 50 percent increase in time over the cursor key for the enter key.

The second component of the SAE J2365 is an age multiplier that was originally computed from Manes, Green, and Hunter (1998). In this study, 3 groups of drivers were tested: (1) young, 19-30, (2) middle, 40-55, and (3) older, over 65. The multiplier was computed by averaging keystroke times over the key category and computing the ratio of each age group. The ratio for the middle group was 1.45 and

the ratio for the older group was 2.2. Since SAE J2365 originally called for the older test group to be between the ages of 55 and 65, a multiplier of 1.8 was interpolated (assuming linearity). The most recent versions of SAE J2364 and J2365 have modified the age range to include the ages of 45 through 65. With the modified age range, the new age multiplier specified is approximately 1.7. Since this study was based on drivers aged 55 to 65 (consistent with the prior version of SAE J2365), the comparisons shown use the previous age multiplier of 1.8 for all SAE J2365 calculations.

As shown in Table 17, the 1.53 age multiplier based on the overall mean keystroke times that was found in this study did not compare well with the multiplier of 1.8 that was calculated the same way in Manes, Green, and Hunter (1998) and interpolated for the correct age group. The differences between studies may be partly due to the limited amount of error-free data used to predict the age multiplier as described in the original study by Manes, Green, and Hunter (1998). The destination entry and retrieval tasks with the Ali-Scout were fairly complex, and it was noted in the study that many of the older test participants had not fully learned the entry process which lead to many errors, excess key presses, and mental operations (pauses between keystrokes). These conditions may have increased the performance gap between the younger and older test participants when compared to the current study which used shorter well-practiced tasks to estimate the keystroke times.

Table 17. Summary of age multipliers found in this study (drivers aged 55 to 65).

Category	Keystroke/Task Name	Mean Time		Older to Younger Ratio
		Younger (s)	Older (s)	
Keystroke	Cursor Once	0.98	1.63	1.66
Keystroke	Cursor Additional	0.43	0.53	1.23
Keystroke	Enter Key	0.99	1.54	1.55
Keystroke	Overall Mean	0.80	1.23	1.53
Task	Address Entry (Keyboard)	70.80	145.80	2.06
Task	List Selection (Keyboard)	17.50	36.40	2.09
Task	List Selection (Remote)	21.70	32.50	1.50

Based on the data listed in Table 17, 3 issues with the age multiplier were noted:

1. Differences in the multiplier due to the keystroke type.
2. Possible differences in the multiplier due to input device.
3. Possible differences in the number of mental operations between age groups.

First, the age multiplier was calculated using the mean keystroke time averaged across keystroke types. This method of calculation makes the assumption that the age multiplier is the same for each type of keystroke or that the keystroke-type frequencies are roughly equivalent. While the cursor once and the enter key produced similar age multipliers (an average of 1.6), the age multiplier for additional cursor keystrokes was much less (1.23). The assumption of a single age multiplier for all keystroke types could lead to an overestimate of the total task time for tasks that contain many repetitive keystrokes.

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Second, as noted in the analysis of the total task times, there was a significant age by device interaction. The average age multiplier based on total task time for keyboard tasks was 2.08, but the average age multiplier for remote controls using the same calculation method was 1.5. This finding would seem to contradict the assumption of a single age multiplier for all devices.

Finally, according to Manes, Green, and Hunter (1998), the older test participants required more mental operations during the tasks until they were fully familiar with the sequence. Some of these additional mental operations would occur between keystrokes, which would alter the resulting keystroke times. One hypothesis which could be drawn from this observation is that the learning rates may factor into the age multiplier. For example, the age multiplier based on keystrokes for a complex task should be greater than the age multiplier for a simple task because the older drivers would have more mental operations embedded between keystrokes. This hypothesis was also supported by the observation that practice appeared to benefit the older drivers more than the younger drivers, which would imply that additional practice would reduce the difference between older and younger drivers. Thus, additional practice would tend to reduce the age modifier.

How did the static task times compare to the dynamic task times?

Two recent studies have compared static task time to dynamic task time: (1) Tijerina (1999), which was reanalyzed by Green (1999a), and (2) Foley et al. (2000). The Tijerina (1999) study used 10 drivers aged 55 to 65 who were given navigation system tasks both statically (parked in a vehicle) and dynamically (while driving on a test track at 45 mph) with the correlation made on an individual trial basis. The Foley et al. (2000) study used 40 drivers aged 46 to 65 who were given 6 tasks (including destination entry, menu item selection, and CD changer tasks) under both static (parked in a vehicle) and dynamic (rural, low-traffic expressway driving) with the correlation made based on the 3 trial average for each task.

To compare the results of this current study with past studies, the static and dynamic task times for the favorites and nearby-facilities list tasks were reanalyzed and plotted in Figure 20. The analysis was based on 2 input devices (keyboard and remote control) performed by the 13 test participants who completed the study (8 younger and 5 older) for a total of 26 data points. The static task times were averaged over 3 trials, and the dynamic task times were averaged over 6 trials of varying workload. The apparent errant data point in Figure 20 has no explanation other than representing an older male test participant who had particular difficulty with using the keyboard while driving.
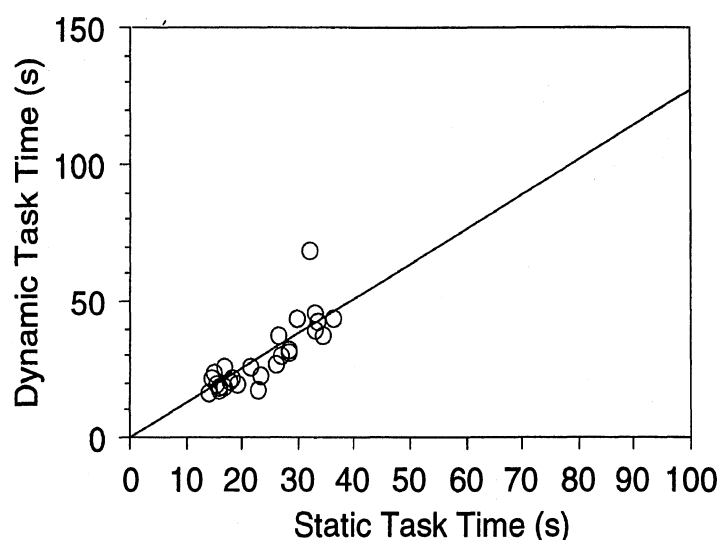
Figure 20. Static vs. dynamic task time averaged over trial and workload (this study).

As shown in Figure 20, the dynamic task times were 1.27 times greater than the static task times (r^2=0.95). This result compared well with Green's (1999a) analysis of Tijerina (1999) which found that the dynamic task time was 1.26 times greater than the static task time (r^2=0.61) for navigation tasks. The Foley et al. (2000) study, however, found that the dynamic task times were 1.70 times greater than the static task time (r^2=0.78), which was much higher than either of the other studies. This could have been due to differences in the duration and complexity of the tasks between studies. Some of the tasks used in Foley et al. (2000) averaged between 40 and 50 seconds (static task time), where the current study only used tasks in the 30 to 35 second range (static task time). The scaling factor may increase as the average task time increases.

How did the driving performance compare to other studies?

There have been many studies that have compared driving performance to total task time including Dingus, Antin, Hulse, and Wierwille (1989), Nowakowski and Green (1998), Tijerina (1999), and Foley et al. (2000). Each study varied in the subject selection and driving conditions (Table 18), but each study found a positive correlation between the total task time and the number of lane excursions. As the total task time increases, the number of lane excursions increases. However, direct comparison between studies has proven difficult because there is no consistent definition or calculation method used to compute the number of lane excursions.

Table 18. Summary of studies examining navigation systems and lane excursions.

Study	# of Subjects	Age Range	Driving Conditions
Dingus, et al. (1989)	32	18-72	Urban/Suburban Streets
Nowakowski and Green (1998)	16	18-72	Expressway (60 mph)
Tijerina (1999)	10	55-65	Test Track (45 mph)
Foley, et al. (2000)	40	45-65	Expressway (65 mph)

The Dingus et al. (1989) paper was based on work with the ETAK navigator. Drivers performed various tasks related to the navigation system, radio, and other vehicle controls while driving. The mean total glance time for each task was computed and plotted against the total number of lane excursions (for all subjects and trials) which occurred while a driver was performing that task. For tasks with a total mean glance time between 0 and 12 seconds, the number of lane excursions was roughly 1.23 times the total mean glance time ($r^2=.44$).

Tijerina (1999) used a similar method to calculate the relationship between the total number of lane excursions and the total task time (instead of the total glance time as described in Dingus et al., 1989). For tasks ranging from 0 to 900 seconds, the number of lane excursions was roughly 0.02 times the total task time (with a y-intercept of .6, $r^2=.80$).

The general problem with this method of calculation is that the total number of lane excursions will depend, in part, upon the exposure (the number of subjects and the number of trials). For meaningful comparisons of the total number of lane excursion, the test condition being compared across studies must be similar.

Nowakowski and Green (1998) used a different approach to deal with driving errors. Lane excursions and speed decreases in excess of 5 mph were identified as driving errors. A single map search task provided the total task times, and trials with driving errors were recorded. The total task times were then categorized into 1 second intervals, and the probability of a driving error for each interval was computed by dividing the number of trials that had a driving error by the total number of trials falling into that interval. A simple linear regression then yielded that the probability of a driving error was approximately 3.5 percent times the total task time less 2 seconds ($r^2=.52$). There were no driving errors for total task times less than 2 seconds, thus below 2 seconds, the probability of a driving error was near 0.

There are problems with the probability approach as well. For example, the calculation method assumed that only 1 lane excursion occurred per trial. While this may be the case for shorter tasks, as the task length increases, the possibility for multiple lane excursions during the same trial increases significantly.

A final method that has been previously used to calculate and report lane excursions was used by Foley et al. (2000). This study used the mean number of lane violations per trial (averaged across subjects) which was then plotted against the mean total task time for each trial of each task (averaged across subjects). For tasks ranging from 10 to 100 seconds in length, the mean lane excursions was approximately 0.016 times the total task time less 3.75 seconds ($r^2=.92$). For tasks less than 3.75 seconds, there would be close to zero lane excursions.

As shown in Figure 21, converting the lane excursions from the current study into a similar format as was used in the Foley et al. (2000) study yielded similar results. The number of lane excursions was averaged across the number of subjects within each age group and the number of trials for each of the 6 tasks (baseline driving, remote control use, and keyboard use by 2 levels of driving demand). For tasks ranging from 0 to 60 seconds in length, the mean number of lane excursions was approximately

0.033 times the total task time with 0.05 lane excursions occurring during baseline driving where the task time is 0 (r^2=.91).

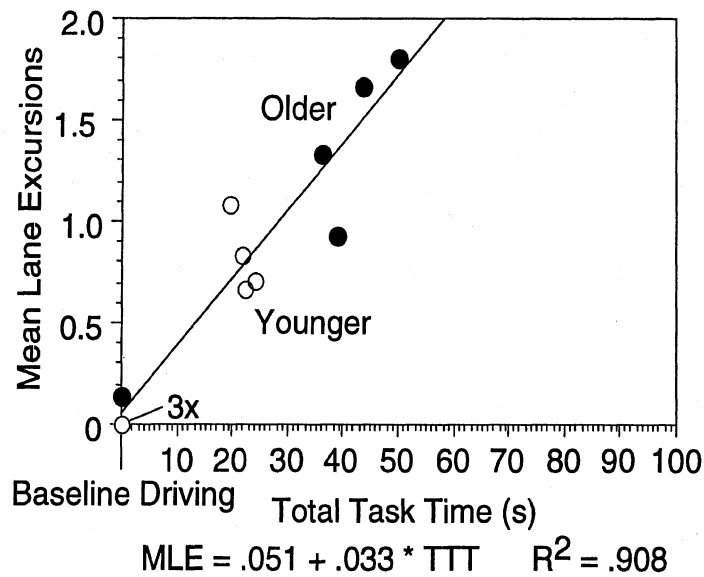MLE = .051 + .033 * TTT R^2 = .908

Figure 21. Mean lane excursions per trial as a function of total task time.

Although mean lane excursions per trial does allow for some comparison between studies, the relationship between total task time and driving performance is likely overrepresented by using lane excursions as a driving performance measure, since longer tasks provide more opportunity for lane excursions. A better driving performance measure might be lane excursions per minute. As shown in Figure 22, using lane excursions per minute as the driving performance measure for this study, there is less pure correlation between driving performance and total task time (r^2=.64). The regression equation predicts that baseline driving results in .4 excursions per minute and each second of task time increases the excursion rate by 0.05 excursions per minute.
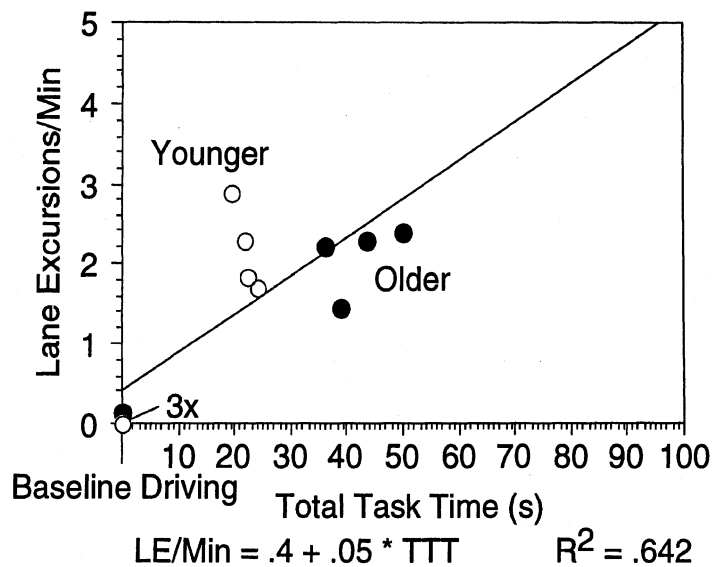

LE/Min = .4 + .05 * TTT R^2 = .642

Figure 22. Lane excursions per minute as a function of total task time.

CONCLUSIONS

1. How much practice should be given before testing?

   The evidence found during this experiment suggests that 5 practice trials, as prescribed in SAE J2364, should be sufficient to reach a stable level of performance. The total task times decreased by an average of 35 to 43 percent between the practice trials and the test trials (for address entry and list selection tasks, respectively). The results also showed that the practice trials were more beneficial to the older (55 to 65 year old) test participants resulting in total task time decreases from 38 to 54 percent between practice and test trials (for address entry and list selection tasks, respectively). Although the 5 practice trials provided a stable measure of novice performance, it was noted that experts with the system averaged 39 to 58 percent faster than even the younger test participants (for address entry and list selection tasks, respectively).

2. How do the measured keystroke times compare to the SAE J2365 keystroke operator estimates, and how do the total task times vary with input device?

   Overall, the measured operator elements for the remote control compared reasonably well to the SAE J2365 keystroke operator estimates. As noted in the discussion, the operator estimates in SAE J2365 were based on the performance of younger test participants. For the elements of cursor keystroke, additional keystroke, and enter keystroke, the SAE J2365 estimates were within 23 percent of the measured times, and the departures from the estimates were reasonable given the design of the remote control.

   There was a slight overall effect for input device, but the effect also varied with age group. The younger drivers performed the tasks 19 percent faster with the keyboard than with the remote control, but the older drivers performed the tasks 11 percent faster with the remote control than with the keyboard.

3. What is the effect of age on keystroke times and total task times?

   As noted above, the operator estimates in SAE J2365 were based on younger drivers, yet SAE J2364 calls for the testing of drivers between 45 and 65 years old. To convert the operator estimates for use with older drivers, an age multiplier of 1.8 was used. The results of this study showed that the age multiplier varied with the input device. For the remote control, the age multiplier was closer to 1.5, while for the keyboard, the age multiplier was closer to 2.0. This study also noted that the age multiplier for repeated keystrokes was much less than the age multiplier for other keystrokes. For repeated cursor keystrokes, the age multiplier was only 1.2.

4. What is the relationship between static (parked) and dynamic (while driving) destination entry task times?

   The dynamic task times found in this study were, on average, 1.27 times greater than the static task times. The road curvature or workload increase from 3 to 6 degree curves did not significantly affect the dynamic task time, although there was

a noted 10 percent decrease in total task time for the 6-degree curves. This was consistent with previous findings, and there was some evidence that the decrease in task time came at the expense of driving performance as the lane variance and the number of lane excursions generally increased as the workload increased.

5. How does destination entry affect driving performance?

There was a significant difference between baseline driving performance and driving performance while using the navigation system. The average lane variance increased between 35 and 58 percent between baseline driving and tasks using the remote control and the keyboard, respectively. The average number of lane excursions also increased from near zero during the baseline driving to 2.6 for tasks with the remote and 3.8 for tasks with the keyboard. The regression equation developed from this study predicts that baseline driving results in .4 excursions per minute and each second of task time increases the excursion rate by 0.05 excursions per minute.

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APPENDIX A – Typical Navigation System Database Description

Overview

The J2364 SAE Recommended Practice for Navigation and Route Guidance Function Accessibility While Driving (1999) specifies that test trials should be of average difficulty for the database in the system being tested. The navigation system tested used a typical 5 state, Great Lakes area database including Illinois, Indiana, Michigan, Ohio, and Wisconsin. Some consider the Midwest to typify the United States, though it lacks some of the Hispanic influence found on the west coast and southeastern part of the United States, and the Asian influence found on the west coast. When entering the destination city or street, the system automatically matched the letters typed to the city or street name within the database. It greyed out characters that could not be entered based upon the characters that had already been entered. This allowed users to enter a city or street name without typing the entire name into the system.

City Selection

Distribution of City Names

An analysis was run to determine the frequency of each letter in the alphabet as a starting character for a city. The most common starting letters each accounted for only 8 percent of the cities in the database. As shown in Figure 23, the most common city starting letters were "B," "C," "M," "S," and "U" which accounted for a total 42 percent of the cities in the database. The letter "U" was an artifact of the database since areas not included in a city were listed under "U" as unincorporated counties. The average length of a city name was 16 characters, but the city names ranged from 3 to 41 characters in length (designated in Figure 23 as the Avg, Min, and Max curves). The longer city names were due to the fact that the database included the city's county and state when multiple entries existed for the same city.
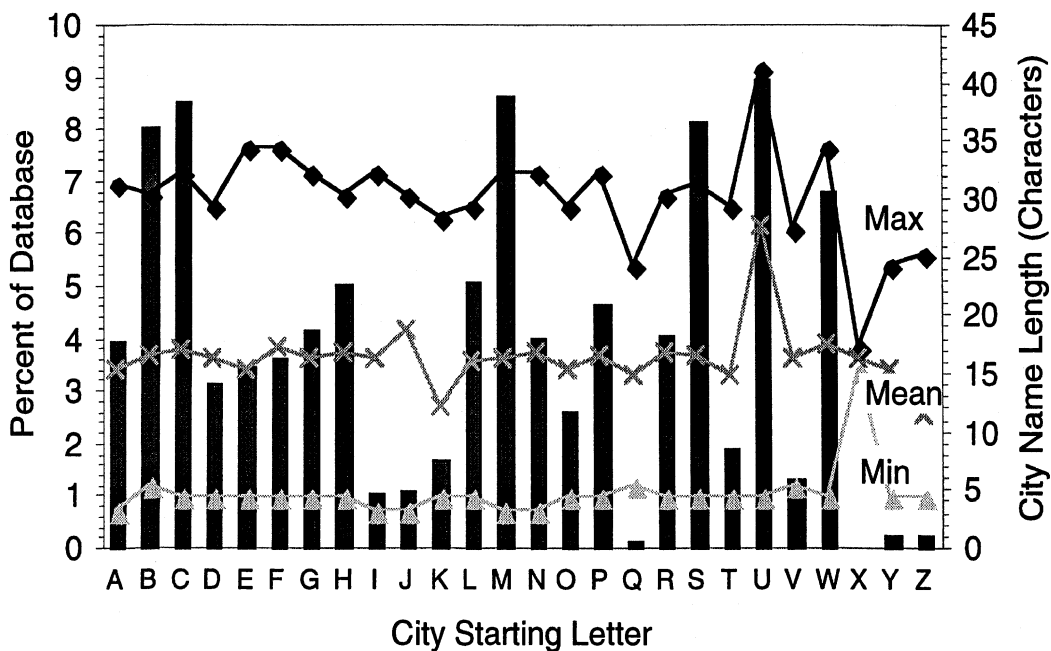

Figure 23. Distribution of cities by starting letter.

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Number of Characters Required to Complete an Entry

A second analysis attempted to determine how many characters had to be entered to select a city from the database. The analysis assumed that the interface contained a selection window of variable size capable of showing a short list of city or street names. The system matched the current letters that had been entered to the most probable city in the database. The selection window showed the most probable city and the next "X" number of cities depending on the window size. The database was assumed to be sorted alphabetically. For example, with a selection window size of 5 and the user having entered "A," "N," and "N" into the system, the first item in the selection window would be the city of Ann Arbor as it is the closest match to the entry sequence. The next 4 cities shown in the selection window would be the next 4 cities listed alphabetically in the database.

To select a city name, the user was assumed to spell out the city name until the desired city appears visible in the selection window. Once the desired city appeared in the selection window, the user was assumed to abandon the process of spelling out the city name and use another means to finish the task (such as using the cursor keys to scroll down to the desired city). Four selection window sizes were examined: 1, 2, 5, and 9 cities. A selection window size of 1 corresponded to the condition where the user must continue spelling out the city name until a perfect match was made.

As shown in Figure 24, all of the cities in the database could be selected by entering 8 characters or less. Over 50 percent of the cities could be completely selected (using a selection window of 1 city) by entering 5 characters or less. Given that the average length of a city name was 16 characters and the average number of characters needed to select a city was 4.5, only 28 percent or less of the characters needed to be entered to select a city. Additionally, as the selection window size increased, the number of characters needed decreased.
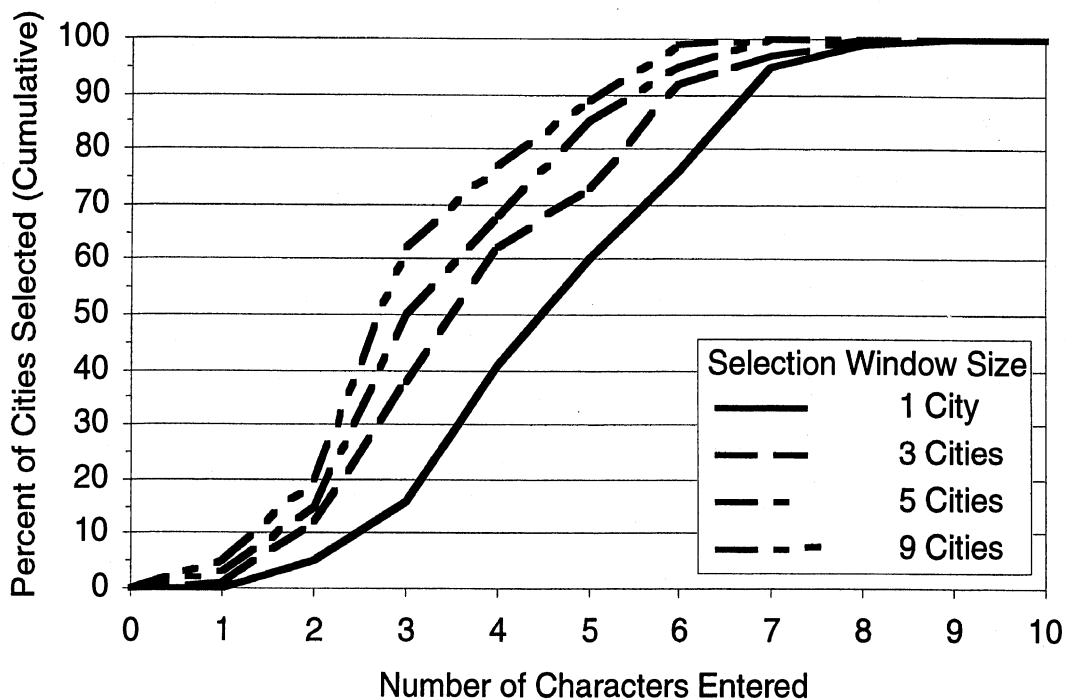

Figure 24. The number of characters required to complete a city name entry.

Street Selection

Distribution of Street Names

The street selection task could only take place after a city was selected. Therefore, 3 cities of various sizes and areas (see Table 19) were selected and analyzed to determine the characteristics of the street names. The population reported for each city was based on the 1990 US Census data. There was little difference in the database summary between Ann Arbor and Detroit (Figures 25 and 26, respectively). However, for the city of Chicago (Figure 27), the majority of the streets began with one of the following 4 letters: N, S, E, or W. This was due to the way the street-name database handled addresses that contained north, south, east, or west. Any street that was divided into north-south or east-west blocks was treated as 2 separate streets (e.g., N_Michigan Ave and S_Michigan Ave). Since Chicago uses a very grid-like street system which is broken into north-south or east-west blocks, almost all of the streets entered into the navigation system for Chicago will start with the characters N, S, E, or W.

Table 19. Summary of street name distributions by city.

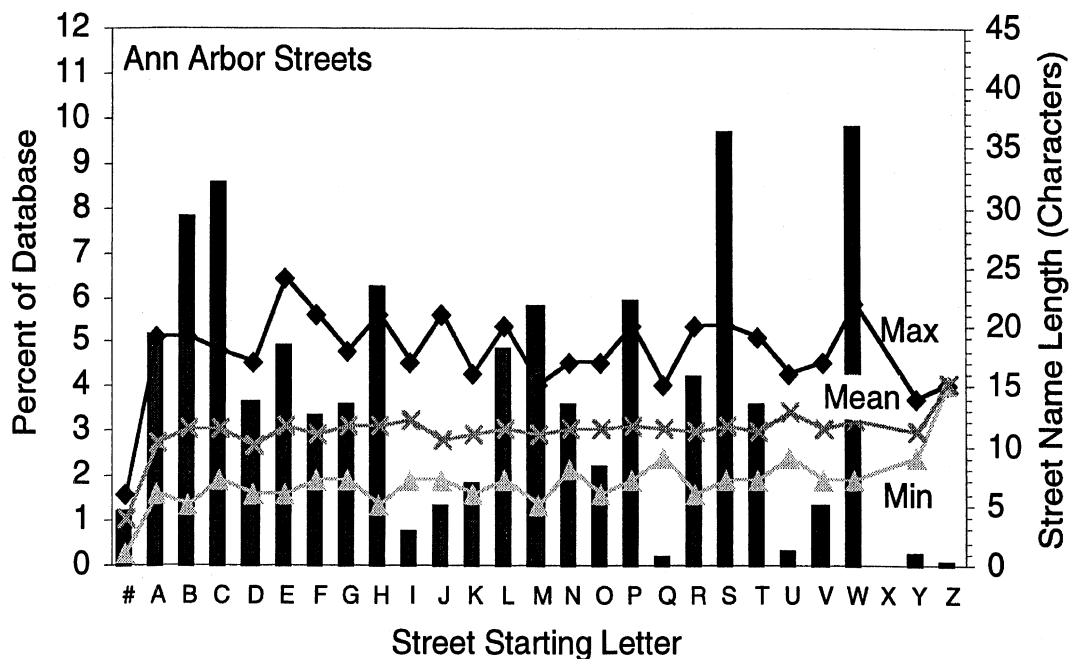| Characteristic	Ann Arbor	Detroit	Chicago
Population	110,000	1,028,000	2,784,000
Area (sq mi)	27	139	230
Top 4 starting letters	W, S, C, B	S, C, M, B	W, N, S, E
% starting with top 4 letters	35.8%	34.3%	91.9%
% starting with top letter	9.8%	10.9%	30.8%
Mean street name length	11.1	10.1	10.5
Characters required. to complete	3.32	3.31	3.85

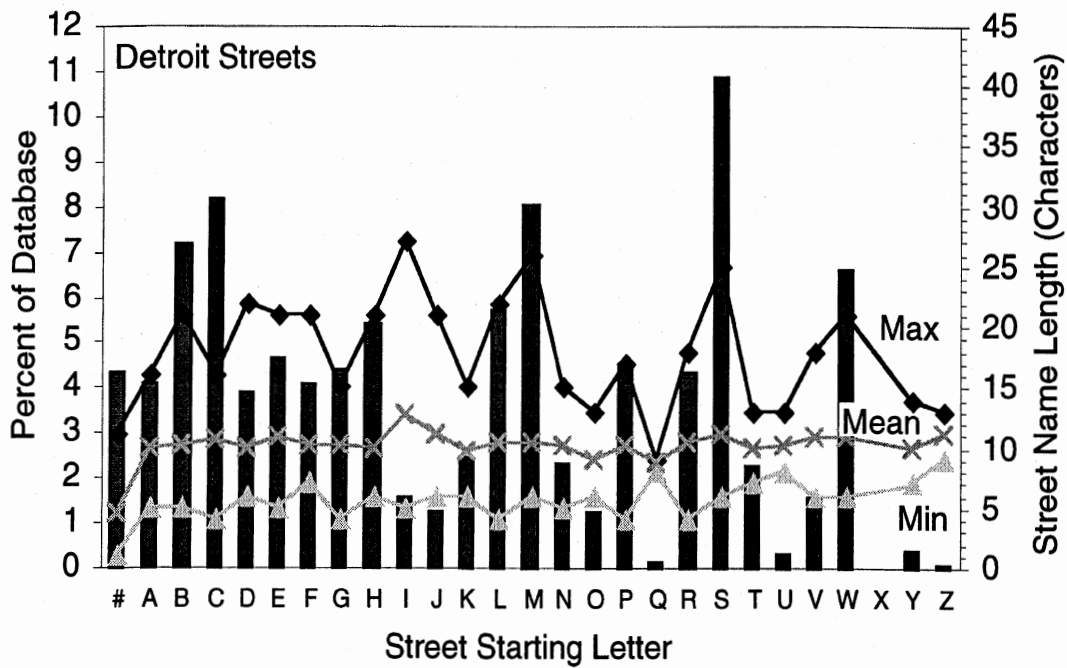Figure 25. Distribution of Ann Arbor street names by starting letter.

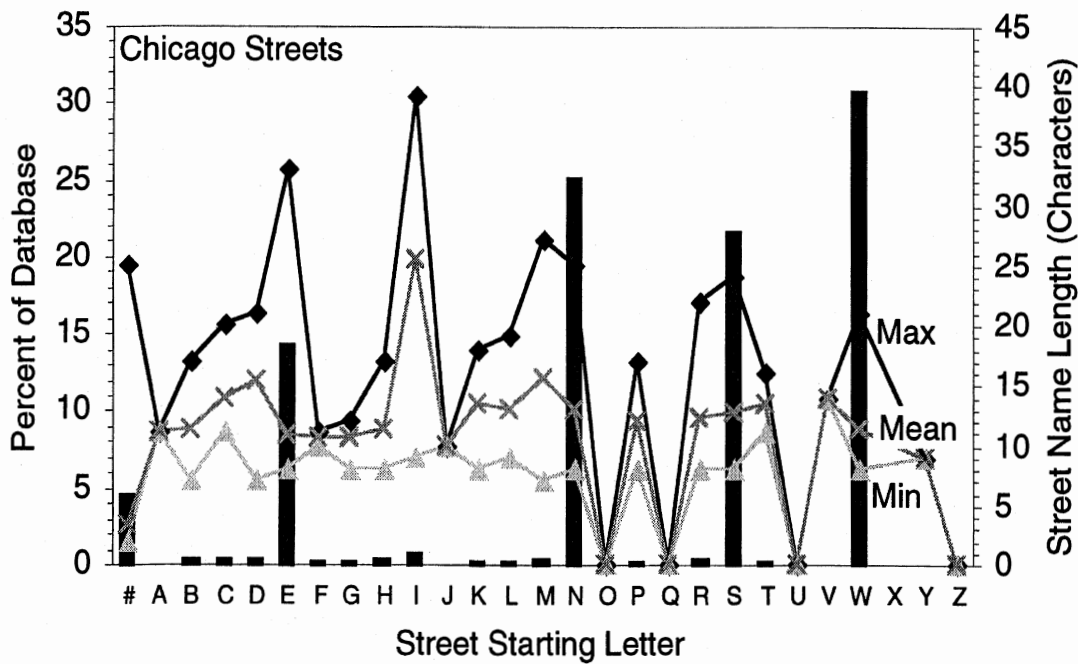Figure 26. Distribution of Detroit street names by starting letter.

Figure 27. Distribution of Chicago street names by starting letter.

After accounting for the north-south-east-west issue, the largest difference noted between the cites involved the percent of streets that were numerically named (e.g., 7th Street). The percent of streets that were numerically named was greater in both Detroit and Chicago than in the smaller city of Ann Arbor. In Ann Arbor only 1 percent of the streets were named numerically, but in the larger cities of Detroit and Chicago, over 4 percent of the streets were named numerically.

Number of Characters Required to Complete an Entry

The streets of Ann Arbor, Detroit, and Chicago were also analyzed to find out how many characters needed to be entered before the desired street was selected. This task was similar to the task of entering a city name into the navigation system, and thus, the same set of assumptions was used:

1. The interface contained a selection window of variable size.
2. The system matched each new letter to the most probable street.
3. The user entered a street name by spelling out the name.
4. The spelling was abandoned once the name appeared in the selection window.

As shown in Figure 28, 29, and 30 (Ann Arbor, Detroit, and Chicago streets, respectively), all of the streets in the database could be selected by entering 8 characters or less. Over 50 percent of the streets could be completely selected (using a selection window of 1) by entering 4 characters or less. The average number of characters required to select a street 50 percent of the time was 3.32, 3.31, and 3.85 for Ann Arbor, Detroit, and Chicago, respectively. Surprisingly, the average number of characters required to select a street in Chicago was only increased by approximately 0.5 even though 90 percent of the streets would require the additional N, S, E, or W prefix and a space before beginning to spell out the actual street name. Similar to the findings of the city selection analysis, as the selection window size increased, the number of characters needed decreased.
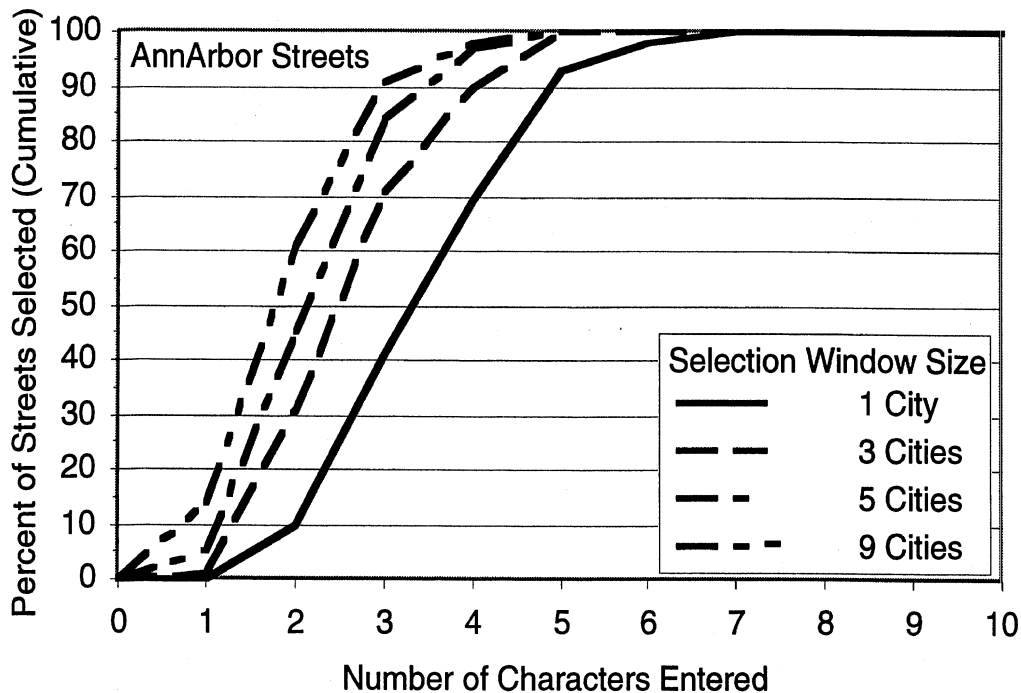

Figure 28. The number of characters required to complete a street entry in Ann Arbor.
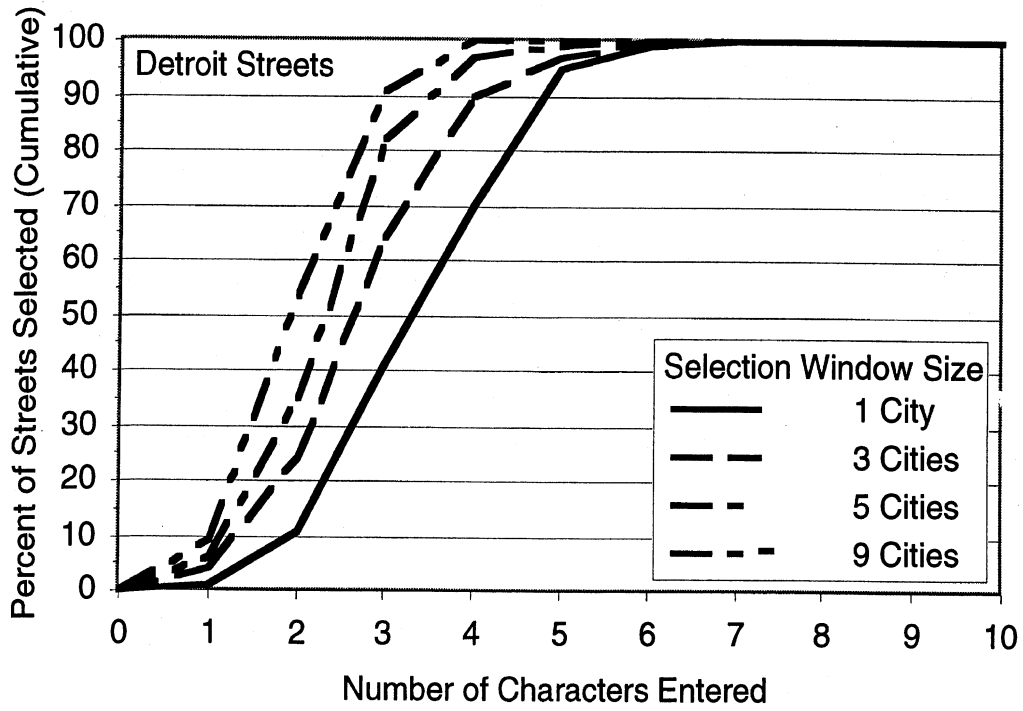
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Figure 29. The number of characters required to complete a street entry in Ann Arbor.

Figure 30. The number of characters required to complete a street entry in Ann Arbor.
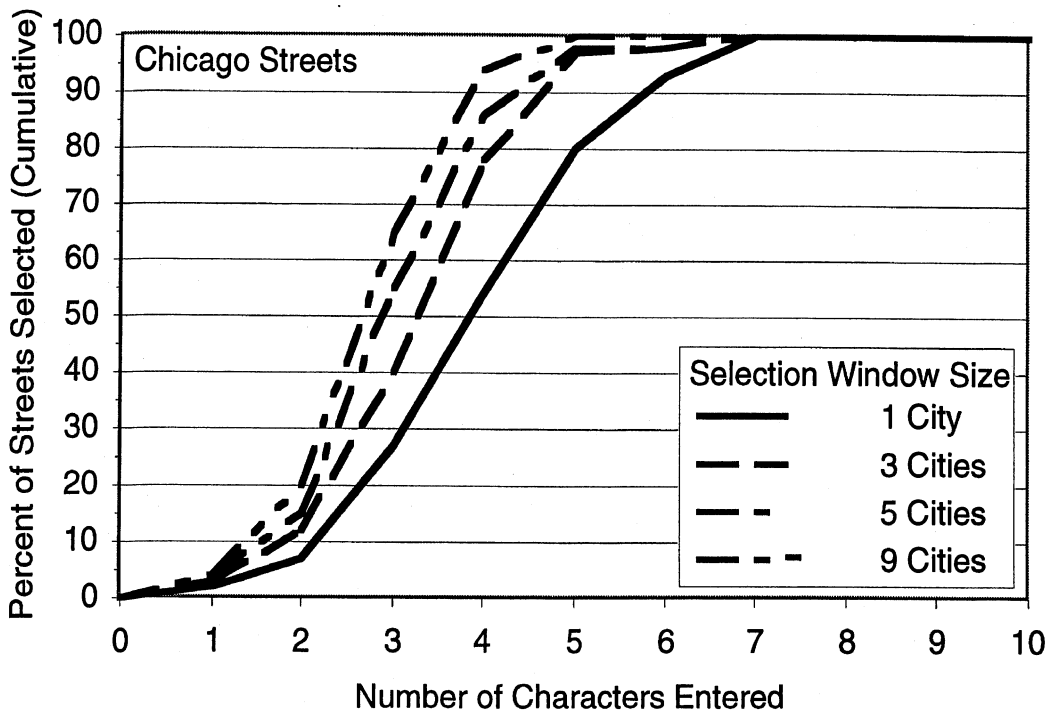
APPENDIX B – Participant Consent Form

PARTICIPANT CONSENT FORM
Laptop Navigation System Destination Entry Study

Several companies are developing software to run on laptop computers to provide directions to drivers while they drive. Because many people already have laptop computers, these systems may offer an advantage over adding an after-market navigation system to a vehicle. This project examines some of the aspects of the safety and usability of using a laptop based navigation system while driving.

In the experiment today, you will spend about 2 hours using a laptop based navigation system that runs under Microsoft's Windows 98. Detailed instructions will be provided on how to use the system. During the first part of the experiment (about 1 hour), you will be given about 20 destinations to enter into the navigation system while seated in the UMTRI Driving Simulator. Two input devices, the laptop's keyboard and an optional remote control, will be examined.

After a short break, the second part of the experiment will involve actually driving the simulator while performing the same tasks learned in the first part of the experiment. The simulator will be set on cruise control at 45 mph. You will be allowed to practice driving the simulator until you are comfortable before any tasks are performed. The test roads are broken into 6-8 minute segments. A break can be provided after any segment should you request one.

Some people experience motion discomfort in the simulator. If this occurs, please tell the experimenter immediately, and he will stop the experiment. You can withdraw from the study at any time and for any reason. You will be paid regardless.

If you have any questions, please do not hesitate to ask the experimenter at any time.

Thank you for your participation.

It is ok to show segments of my test session in presentations to UMTRI visitors, UMTRI papers and reports, and on conferences and meetings. (This is not required for participation in the study but is useful to have. Your name will not be mentioned.)

I agree_____   I disagree_____

I have reviewed and understand the information presented above. My participation in this study is entirely voluntary.

Subject Name (PRINTED)   Date

Subject Signature   Witness (experimenter)

Investigator: Paul Green 763-3795

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APPENDIX C – Test Participant Biographical Form

Pre Test Biographical Form

University of Michigan Transportation Research Institute
Human Factors Division

Subject: [____]

Date: [____]

Name: _____

Male   Female (circle one)   Age: _____

Occupation (or major): _____

How many times have you driven the UMTRI Simulator? _____

What is your primary vehicle?

Vehicle Year/Model: _____   Annual Mileage: _____

In the last **6 months**, how many times have you used a paper map?

   0   1-2   3-4   5-6   7-8   9 or more

...An internet based mapping or directions site (e.g., Mapquest or Yahoo)?

   0   1-2   3-4   5-6   7-8   9 or more

How often do you use a computer?

  Daily   A few times a week   A few times a month   Once in awhile   Never

How often do you use a laptop computer?

  Daily   A few times a week   A few times a month   Once in awhile   Never

What operating systems do you use most often?

  Windows   Macintosh   Linux   Unix   (Other)_____

Have you ever driven a vehicle with an in-vehicle navigation system?

  Never   Only in an experiment   Yes, elsewhere   (What kind?_____)

TITMUS VISION: (Landolt Rings)

Vision correctors?   Y / N

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	20/100	20/70	20/50	20/40	20/35	20/30	20/25	20/22	20/20	20/18	20/17	20/15	20/13

which?

APPENDIX D – Experiment Protocol

Pre-Experiment Setup

1. Prepare packet including a consent form, biographical form, and payment form.
2. Start up the simulator and navigation system.
3. Set the vehicle position in the navigation system to Vehicle Position 1 (Favorites).
4. Set the destination as Arborland Mall (Favorites).
5. Disable the menu bar and tool bar and hide the cursor in the lower right corner.
6. Quit and restart the navigation system.

Pre-Experiment Forms

1. Welcome the test participants to UMTRI.
2. Read and have the test participants sign the consent form.
3. Have the test participants fill out the Biographical Form.
4. Vision Test

Introduction to the Mitsubishi Navigation System

1. Allow the test participants to adjust the simulator car seat.
2. Calibrate the Simulator.
3. Make sure the in-vehicle light illumination light is on and the room lights are off.
4. Start the simulator at the stoplight.
5. Explain how the system works with keyboard operation using the following tasks:

- Change the view to "Destination"
- Change the view to "Current"
- Activate the Favorites list. Cursor down or right. Cursor up or left. Use "Next." Use "Previous." Explain that the items are sorted alphabetically. Select Arborland Mall with the enter key. Use the enter key to Click "Ok." Cursor up to "Set Destination" and use the enter key. Use the enter key to click "Ok."
- Activate the "Address/Facility" menu item. Explain that first you must select the country. Cursor down from the select button to the alphabet bar. Select "U" with the enter key. Use the enter key to click "Select." Explain that next it wants the city name. Cursor down from the select button to the alphabet bar to the letter "A" for Ann Arbor. Continue spelling out Ann Arbor until it is highlighted in the list above, then cursor back to the select button and press enter. Explain that next it wants to know what it is searching for. Cursor down from the select button to "A" for address. Use the enter button to click "Select" for address. Explain that next it wants the street name. Cursor down to the alphabet bar to the letter "P" for Plymouth Road. Continue spelling out Plymouth until the road appears highlighted. Then use the select button to select it. Explain that next it wants the address range. Again, cursor down to the alphabet box and use the numbers to type out the address range. Select 1, 5, 7 to select the address range from 1577-1725. Use enter to click the "Select" button. Use enter to click "Ok." Cursor up to "Set Destination" and use the enter key to select it. Use enter to click "Ok."

6. Explain how the system works with remote control operations:

- Change the view to "Destination"
- Change the view to "Current"
- Activate the "Around Vehicle" menu item which brings up the nearby facilities list. Notice that the format is similar to the favorites list. Cursor down or right. Cursor up or left. Use "Next." Use "Previous." Explain that the items are sorted categories that are displayed alphabetically. Within each category, the items are sorted from nearest to furthest away. Select "Bank" by pressing down on the thumb stick (which is equivalent to the enter key). Cursor down to NBD Bank and select it in the same way. Use the thumb stick enter button to click "Ok." Cursor up and select "Set Destination." Use the enter key again to click "Ok."

Address Entry Practice – Keyboard

1. Instruct the test participant to use the keyboard for these trials.
2. Provide a 3x5 card for each trial with the address.
3. During Trial 2, instruct the test participant on how to enter W. Golf Lane.

Trial	Address
1.	20200 Huntington Road, Detroit (Wayne, MI)
2.	400 West Golf Lane, Indianapolis
3.	20400 Sheffield Road, Detroit (Wayne, MI)
4.	10 Bryant Road, Lexington (Fayette, KY)
5.	7600 Conrad Street, Detroit (Wayne, MI)

Nearby/Favorites List Practice – Remote Control

- Instruct the test participant to use the remote control for these trials.

Trial	Target Destination
1.	Select Just Jewelry from the Favorites list.
2.	Select Oakwood Hospital from the Nearby Facilities list.
3.	Select the Nearest Marathon Petrol Station from the Nearby Facilities list.
4.	Select Quantum Controls from the Favorites list.
5.	Select the University of Michigan Parking Lot from the Nearby Facilities list.

Change Vehicle Position

1. Experimenter changes the vehicle position to VP 2 from the favorites list.
2. Experimenter sets the destination to Quantum Controls from the favorites list.

Address Entry Test – Keyboard

1. Instruct the test participant to use the keyboard for these trials.
2. Provide a 3x5 card for each trial with the address.

Trial	Address
1.	33000 Vermont Street, Livonia (Wayne, MI)
2.	10 North 7th Street, Millwaukee
3.	53350 Abraham Drive, Macomb (Macomb, MI)

Nearby/Favorites List Test – Remote Control

- Instruct the test participant to use the remote control for these trials.

Trial	Target Destination
1.	Select the Novi Expo Center from the Favorites list.
2.	Select the Royal Inn – Livonia Hotel from the Nearby Facilities list.
3.	Select the Cobo Conference-Exhibition Center from the Favorites list.

Nearby/Favorites List Test – Keyboard

- Instruct the test participant to use the keyboard for these trials.

Trial	Target Destination
1.	Select the nearest Sunoco Petrol Station from the Nearby Facilities list.
2.	Select the Garden Center (Frank's Nursery) from the Favorites list.
3.	Select the Wonderland Mall Shopping Centre from the Nearby Facilities list.

Break

- Offer the test participant a 5 minute break.

Driving Practice 1 – No Secondary Task

1. Calibrate simulator (if not already done).
2. Explain the vehicle controls and cruise control.
3. Load the first practice road and let the test participants drive it.
4. Periodically ask about motion sickness.

Driving Practice 2 – Keyboard

1. Load the second practice road.
2. Instruct the test participant to use the keyboard for these tasks.
3. Explain that while driving this road, they will be asked to perform several tasks while driving using the keyboard. The first few will be simple, such as changing the view while driving on a long straight road section. As they get more comfortable, the tasks will get a little more difficult. Eventually, we will try re-entering a few of the destinations we did in the last task.

Trial	Task
1.	Use the menu to change the view to "Destination"
2.	Use the menu to change the view to "Current"
3.	Open the Favorites list, then cancel it.
4.	Select the nearest Sunoco Petrol Station from the Nearby Facilities list.
5.	Select the Novi Expo Center from the Favorites list.
6.	Select Wonderland Mall Shopping Centre from the Nearby Facilities list.

Driving Practice 3 – Remote Control

1. Load the third practice road.
2. Instruct the test participant to use the remote control for these tasks.

Trial	Task
1.	Open the Favorites list, then cancel it.
2.	Open the Nearby list, then cancel it.
3.	Select the Cobo Conference-Exhibition Center from the Favorites list.
4.	Select the Royal Inn – Livonia Hotel from the Nearby Facilities list.
5.	Select the Garden Center (Frank's Nursery) from the Favorites list.

Change Vehicle Position

1. Experimenter changes the vehicle position to VP 3 from the favorites list.
2. Experimenter sets the destination to the Garden Center from the favorites list.

Driving Test Road 1 – Keyboard

1. Load the first test road.
2. Instruct the test participant to use the keyboard for these tasks.

Trial	Task
1.	Select the Best Western Hotel from the Nearby Facilities list.
2.	Select Motorola Automotive from the Favorites list.
3.	Select the Standard Federal Bank from the Nearby Facilities list.
4.	Select Quantum Controls from the Favorites list.
5.	Select Just Jewelry from the Favorites list.
6.	Select Maggies's Coffee House Restaurant from the Nearby Facilities list.

Change Vehicle Position

1. Experimenter changes the vehicle position to VP 4 from the favorites list.
2. Experimenter sets the destination to the Just Jewelry from the favorites list.

Driving Test Road 2 – Remote Control

1. Load the second test road.
2. Instruct the test participant to use the remote control for these tasks.

Trial	Task
1.	Select the Detroit Receiving Hospital from the Nearby Facilities list.
2.	Select the nearest Mobil Petrol Station from the Nearby Facilities list.
3.	Select Lilley Park from the Favorites list.
4.	Select Cadillac-Farmer Parking Lot from the Nearby Facilities list.
5.	Select Arborland Mall from the Favorites list.
6.	Select Orchard Lake Deli and Ribs from the Favorites list.

Posttest

1. Load the road with the stoplight.
2. Instruct the test participant to use the remote control for these tasks.

Trial	Task
1.	Select the Emanuel Steward's Restaurant from the Nearby Facilities list.
2.	Change the view to the "Destination."
3.	Select Eddy's Home from the Favorites list.
4.	Change the view to "Current."
5.	Select Michigan National Bank from the Nearby Facilities list.

Postexperiment

1. Thank the test participant for their participation.
2. Fill out the payment form and pay the test participant.