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HUD Feedback to Minimize the Risk of Cellular Phone Use and Number Entry While Driving

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16. Abstract

There has been considerable public debate as to whether people should be allowed to use cell phones while driving. In several countries, this debate has led to restrictions on cell phone use while driving. Japanese data suggests that answering a call might be the most dangerous task, followed by dialing. Several questions were therefore selected for further investigation.

1. How does the dialing device and its location affect task time, errors, driving performance, and ratings of workload?
2. How does the location of the display (especially head-up displays) affect those same measures?
3. For various control-display combinations, how are those measures affected by driving workload?

The experiment will be comprised of two distinct portions. In the first portion, subjects will drive a simulator on straight roads (implying controlled workload) while dialing a 10-digit telephone number using 6 device configurations with various displays. During the second test portion, participants will drive a simulator on roads with curves of different radii while entering phone numbers for 3 different device combinations. The following device/location configurations will be examined: (1) 10-key keypad on the steering wheel spoke, (2) 10-key keypad on the center console, (3) joystick on the steering wheel spoke, (4) joystick mounted on the center console, (5) hand held 10-key keypad, (6) a cross key on the touch screen, and (7) a 10 key keypad on the touch screen. These devices will be used for 3 display conditions: (1) head up display, (2) monitor mounted in the center console, or (3) no display.

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TABLE OF CONTENTS

INTRODUCTION

There has been considerable public debate as to whether people should be allowed to use cell phones while driving, especially in the U.S. (Intelligent Transportation Society of America, 2001, Joint State Government Commission, 2001). Typing the phrase "cell phone safety" into google.com leads to several well known sites on the topic including the Advocates for Cell Phone Safety (Patty Pena's site, www.geocities.com/morganleepena/), the report of the National Highway Traffic Safety Administration on cell phone safety (www.nhtsa.dot.gov/people/injury/research/wireless/), and the car talk web site (cartalk.cars.com/About/Drive-Now/), a site associated with a popular public radio program on car repair. The topic has been the topic of popular programs dealing with investigative news, such as the ABC program 20/20 (abcnews.go.com/onair/2020/2020_991020cellphones.html).

This debate has not been limited to the U.S. In several countries, this debate has led to restrictions on cell phone use while driving, either outright bans or limited use to hands-free only. Such restrictions are in place in Japan.

Japanese action was stimulated by crash data from the Japanese National Police Agency. Data available from before the ban was enacted (January-November 1999) suggests that answering a call might be the most dangerous task (1077 crashes) followed by dialing (504 crashes), talking (350 reports), and other (487 reports) (Green, 2000).

Dialing was examined by Nowakowski, Friedman, and Green (2001), a previous experiment in this series. They found that for driving in a simulator, the time to answer the phone was extremely short, typically 1 to 4 seconds and often just after the first ring. Further, they found that presenting the CallerID on a head-up display (HUD) was less distracting (degraded driving performance less) than presenting that information on a hand-held phone.

Given the merits of a HUD in reducing the crash risk of answering the phone, examining the use of a HUD for other phone-related tasks makes sense. Since dialing was the second most common tasks associated with crashes, this task was examined.

For dialing tasks, not only is the display important, but so too is the control. In fact, one potential solution to the manual entry problem is to substitute voice controls. To gain insight into this, UMTRI recently completed a study for Mitsubishi Motors on navigation system destination entry using a touch screen and 2 voice entry methods (word-by-word and character-by-character). At this point the results are proprietary, but they should be released shortly.

For reasons of cost constraints and limited instrument panel space, motor vehicle manufacturers are looking towards more integrated driver information systems, and that includes integrating cellular phones. Thus, the use of shared device controls and displays is becoming more common, initially in luxury vehicles. For example, BMW's I-drive system, the Mercedes COMMAND system, and the Lexus system all have integrated cellular phones, and controls and displays shared with other vehicle telematics.

Specifically, the BMW system uses a large round controller to navigate though menu items, pushing down on the device acts as the enter button. A numeric telephone keypad is accessible via a small drawer on the center console stack. The display for all of these devices is in the middle of the dash at the top of the stack. This display is shared with many of the vehicles' infotainment and climate control systems, as well as other telematics devices.

The Mercedes system, COMMAND, shares a display between the radio, navigation system, audio system and cellular telephone. The main functions are selected by a rotating knob on the center console stack adjacent to the display. A numeric keypad is located above the rotating knob for dialing.

The Lexus system uses a touch screen for both display and data entry. The system displays changing options along the left and right sides of the display flanked with hard key switches for selection. Soft keys on the touch screen are used for radio settings, cell phone number entry, and destination entry for the navigation system.

The controls and displays provided affects how a phone number is dialed. Further, a driver may dial the entire 7, 10, or 11 digit number, use a speed dial short cut feature, utilize a menu driven address book function to lookup and dial a number, or use a voice activation device and say "call home" or "dial 9636081." All of these methods are available and in use today, even on hand-held units.

Review of the literature and consideration of information needed to support future product design has indicated the following issues need attention:

1. How does the control device and its location (e.g., hard keys (steering wheel spokes, center console), touch screen (center console), hand held remote, joystick (spoke, center console) affect task time and driving performance?

2. How does the location of the display (e.g., HUD, center console (and also on hand-held for hand-held) affect task time and driving performance?

3. How are dialing task time, driving performance, and driver preferences for different control-display combinations affected by the driving workload?

Within the context of this study, it is not possible to test every possible control and display of interest. Therefore, this project will attempt to test as many combinations as possible within the project resources, and by careful selection of the test conditions, model the others using GOMS (Card, Moran, and Newell, 1980), SAE J2365 (Society of Automotive Engineers, 2002), and other approaches.

Preliminary Study

Overview

A pilot study was designed to provide insight into the behavior of the driver while performing a secondary task, dialing. Specifically of interest was the effect of different input devices, display types, and their locations on total task time. All proposed dialing device configurations were tested (see Table 1) under the premise that the factors could be narrowed down for the final study. Therefore, two test blocks were run where participants were asked to dial a memorized 10-digit number on 15 dialing device configurations. The secondary task was performed while the simulated vehicle was parked and while driving on a straight one-lane road during the first and second block, respectively. Task completion time and glance behavior was collected for 15 device/location/display combinations.

Test Plan

Two subjects volunteered to participate in the pre-pilot study. Both were 20-year-old male engineering students who worked at UMTRI in the Human Factors Division.

Four devices (10-key keypad (touch screen and hard keys) and 5-key cross key (touch screen and hard key), two device locations (center console and steering wheel), and three displays (center console, HUD, none) were selected. In addition, the dialing task was completed in both static and dynamic driving scenarios. Collected data included task completion time and eye glance behavior. The summary of dialing task factors along with their respective task completion times for the dynamic task can be found in the key findings (Table 1).

The 10-key keypad, a standard numeric keyboard altered to simulate a telephone keypad, was mounted on the steering wheel or the center console. The 10-key touch keypad was also modeled after a standard phone keypad. Both keypad devices required only one keystroke per digit dialed. The 5-key cross key device was the same numeric keyboard, however the 8, 2, 4, 6, and 5 keys simulated up, down, left, right, and enter movements of the display cursor. The cross key display, also modeled after the telephone keypad, showed a cursor that indicated the selected. The 5-key touch cross key device was designed in the same manner, where five buttons, up, down, left, right, and enter, controlled the device. Both cross key devices were operated by pressing the directional keys to move a cursor, located on the corresponding telephone keypad display, to the desired digit and then pressing enter to select it. Once the digit was selected, the cursor returned to its default position (number 5 or center of the keypad). An illustration of this device and display can be seen below in Figure 1.

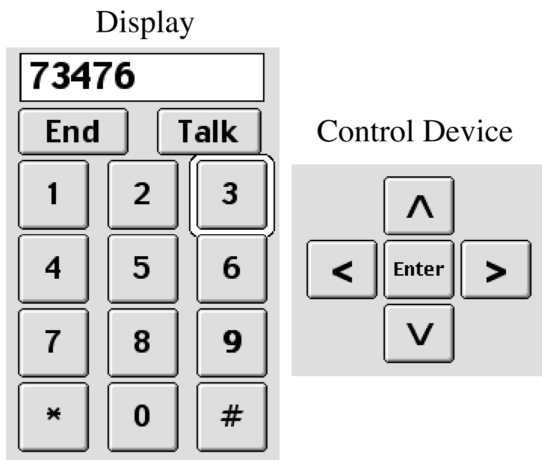


Figure 1. Five-key touch cross key display and device

Prototypes of the touch screen devices and displays were developed with RealBASIC. The program could collect the total task time for every trial as well as manipulate the device, location and display factors to produce 15 different device combinations. The touch screen devices were limited to the center console location and the no display condition was limited to the keypad devices, thus only 15 combinations were tested and not 24.

The UMTRI driving simulator was used to create two driving scenarios: (1) parked at a red stoplight (static) and (2) a straight, one-lane road on which the participants drove while performing the tasks (dynamic).

The subject was first asked for four 10-digit telephone numbers that were most familiar to them (e.g. home, mobile, parents' home, companion's home, etc.). A brief introduction was given and the subject practiced using each device. Next, the parked portion of the study began. The subjects were asked to dial a specified phone number using a specified device combination. The task was repeated three times using the same device combination but a different phone number was dialed. The same process was repeated for all device combinations. Finally, the subjects were asked to drive on the straight road and complete the dialing tasks in the same manner as the parked portion of the experiment. Task completion time was collected during the experiment, and eye glance behavior was captured on camera.

Results

Table 1. Summary of dialing task factors and their respective task completion times.

	Input Device	Input Location	Display Location	TCT (dynamic)
1	10-key touch keypad	Center Console	Center Console	3.39
2	10-key touch keypad	Center Console	HUD	5.69
3	10-key touch keypad	Center Console	None	3.91
4	5-key touch cross key	Center Console	Center Console	7.12
5	5-key touch cross key	Center Console	HUD	6.47
6	10-key keypad	Center Console	Center Console	6.29
7	10-key keypad	Center Console	HUD	5.99
8	10-key keypad	Center Console	None	7.14
9	10-key keypad	Steering Wheel	Center Console	6.23
10	10-key keypad	Steering Wheel	HUD	17.56
11	10-key keypad	Steering Wheel	None	17.77
12	5-key cross key	Center Console	Center Console	18.28
13	5-key cross key	Center Console	HUD	17.98
14	5-key cross key	Steering Wheel	Center Console	27.10
15	5-key cross key	Steering Wheel	HUD	31.24

First, task completion times (TCT) were predicted using the SAE J2365 model for static in-vehicle navigation and route guidance tasks. However, the estimations did not take into account output devices, thus the model could not accurately predict TCT for the devices whose output was displayed in a different location. In addition, the model was based on input times for hard key devices and should be adjusted for the touch screen input devices. Nevertheless, the average static TCTs for each keypad and cross key combination were within ±3 seconds of the J2365 prediction (with two exceptions). The model predicted a TCT of 6.2 sec and 6.5 sec for a 10-key keypad located on the steering wheel and center console, respectively. The predicted TCT for the cross key located on the steering wheel and center console was 20.3 sec and 20.5 sec, respectively. Also important to note was the insignificant difference between the overall average TCT for static and dynamic data. Thus, average TCT will hereafter refer to the dynamic data.

The most obvious effect was that of input device on average task completion time and eye glance behavior. First, the cross key devices required twice as many keystrokes to dial a 10 digit number, resulting in TCTs more than 3 times as long. The average TCT for the 10-key devices was 6.5 seconds while the average for the cross key devices was 23.5 seconds. Similarly, the cross key devices required about twice as many glances away from the road when the display was located on the center console. The subjects could enter between 2 and 5 numbers in one glance away from the road when using the 10-key devices while they could only enter 1 to 2 numbers when using the cross key devices. These observations did not consider the HUD display conditions, as it was not possible to differentiate between looking at the HUD display and the road. Next, the touch screen and hard key devices produced TCTs that varied according to the type of device. The 10-key devices showed no difference in average TCT for touch and hard keys (6.5 sec) while the average TCTs for the cross key devices were 29.2 sec and 18.1 sec for the touch and the hard cross keys, respectively. Figure 2 is a graphical summary of the average task completion time for the 10 key and cross key dialing devices.

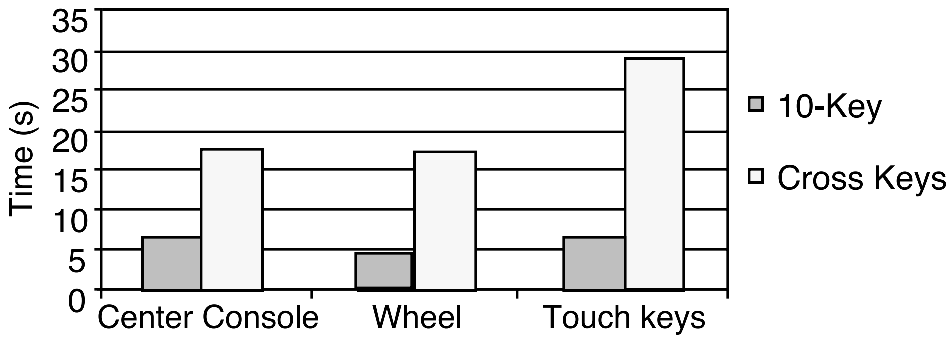


Figure 2. Input device effect

Next, the device location only slightly affected task completion time. Subjects dialed slightly faster when the 10-key keypad device was positioned on the steering wheel. The average TCT for this device on the wheel was 4.3 sec while the average TCT was 6.5 sec when the device was on the center console. However, the location effect was not so prominent for the cross key device; the difference was less than one second. Figure 3 graphically represents the average task completion time for both types of devices when placed on the wheel and center console.

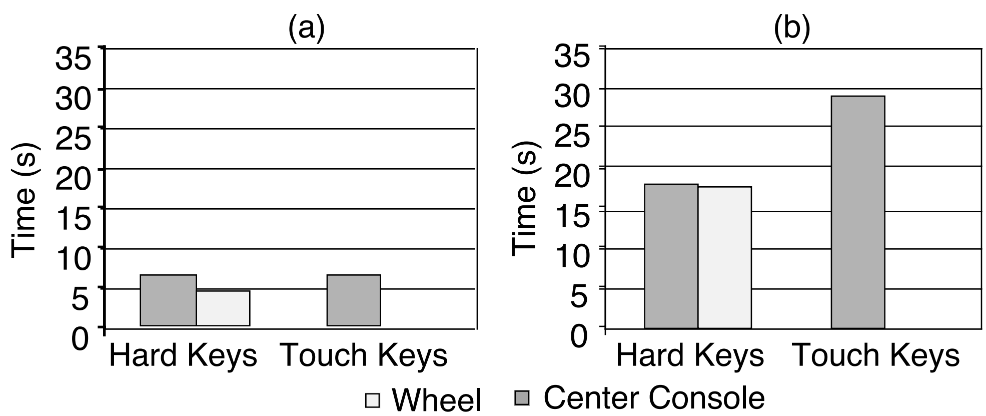


Figure 3. Location effect for (a) cross key device and (b) 10-key device

Finally, the display type had a minimal affect on task completion time. There was only a slight difference between the center console and no display conditions and between the center console and HUD display conditions for all the 10-key devices. The same was true for the cross key devices.

Summary and Limitations

1. The average static task completion times were comparable with the SAE J2365 predicted task completion times.

2. Device type greatly affected the amount of time it takes to dial a number. The large difference in task completion time seemed to come from the number of keystrokes required to dial a number.

3. The location of the devices only slightly affected task completion time when the 10-key device was used.

4. Display location had a minimal affect on task completion time.

Table 2. Limitations and implications of pilot study

Limitations	Implications
Subject population very limited: both males in same young age group, both engineering students	Data not representative of all driving populations; task times expected to be much greater for older drivers
Cross key device prototype not an adequate representation of a cross key or joystick	TCT slower than expected
Size of the hard keys was not realistic	TCT faster than expected due large size of buttons
Cross key display could be designed in multiple fashions (3x3 vs. 2x5)	May be able to reduce the number of glances if design is different
Dynamic road scenario was not a realistic: no traffic, single lane, no curves	Not representative of a normal driving situation; dynamic task times were not significantly different than static

TEST PLAN

Overview

This experiment will examine the relationships between different input devices, device locations, displays and display locations used in dialing an integrated cellular telephone while driving a vehicle. The experiment will be comprised of two distinct experimental blocks. In the first portion, subjects will drive a simulator on straight or gently curving roads with controlled workload while dialing a 10-digit telephone number using 6 of the device/location configurations. During the second portion, participants will drive a simulator on roads with curves of different radii while entering the telephone numbers on three different device/location and display combinations.

The following device/location configurations will be used during the experiment: (1) 10-key keypad on the steering wheel spoke, (2) 10-key keypad on the center console, (3) joystick on the steering wheel spoke, (4) joystick mounted on the center console, (5) hand held 10-key keypad, (6) a cross key on the touchscreen, and (7) a 10 key keypad on the touchscreen. These devices will be used with 1 of 3 display types: (1) head up display, (2) monitor mounted in the center console, or (3) no display. Due to product and time constraints, not all control combinations will be explored. Speed and accuracy of the number entry, detailed driving performance measures, and subjective ratings of workload and safety will be recorded and analyzed.

Test Participants

Twenty-four drivers will be recruited to participate in this study. The will be evenly divided into two age categories: young (20 to 30 years old) and old (65 and older). Within each age category, there will be an equal number of men and women. The subjects will be recruited via the UMTRI participant database and screening will occur to eliminate non-cell phone users. Therefore, all participants may have reported some experience operating a cellular telephone while driving. Each will receive $40 as payment for their participation.

Participants' vision will be tested using a vision tester (Optec 2000, Stereo Optical Inc.) for far visual acuity. All will have far visual acuity of 20/40 or better, as required by Michigan State law for driving (day and night).

Experimental Design

The study will examine the effect of various dialing device configurations (input device, location, and display) while driving on a simulated road. Two separate experimental conditions (a single and multiple levels of visual demand) were designed to determine the effect of increased workload on driving performance and secondary task performance.

A low visual demand will be fixed during the first condition, as all test trials will be performed on a straight or gently curving road. Several dialing devices were configured for six test blocks: (1) 10 key keypad on the wheel, (2) 10 key keypad on the center console, (3) joystick on the wheel, (4) joystick on the center console, and (5) 10 key keypad on the hand held remote. A sixth touch screen device (in the center console location) will also be configured to resemble a 10 key keypad. The display for each dialing device configuration will be placed in three locations: (1) head up display, (2) touch screen on the center console, and (3) no display.

Table 3 shows the combinations to be explored. For reasons of cost, not all possible combinations were explored. Further, some combinations did not make sense to explore. In selection combinations to examine, a few extreme cases were selected to provide estimates of the range of performance possible, though most cases were selected because they might be included in a production vehicle. A few combinations were included because the results from them would help with modeling the conditions not examined.

Table 3. Proposed Combinations to be Examined

		Display location			
Control	**Location**	No display	HUD	Center console	On hand held
Hard keys	Steering wheel	X	X	X	
	Center console		X	X	
Cross Key	Touch screen			X	
10 Key				X	
Hand held remote	Hand held remote		X		X
Joystick	Steering wheel		X	X	
	Center console		X	X	

The second portion of the experiment was designed so to examine the effect of workload (as assessed by visual demand) on task performance, possible for 3 levels of workload. This will be accomplished by manipulating the radius of curvature on various road sections (straight or very slight curve, moderate curve, sharp curve). Only three dialing device configurations will be tested: (1) 10 key keypad on the wheel with a HUD display, (2) touch screen cross key on the center console, and (3) joystick on the center console with a center console display.

This tentative experimental design was developed very quickly and may be revised prior to implementation as the experiment is given further thought. In addition, the findings from pilot subjects are likely to lead to improvements in the experimental design.

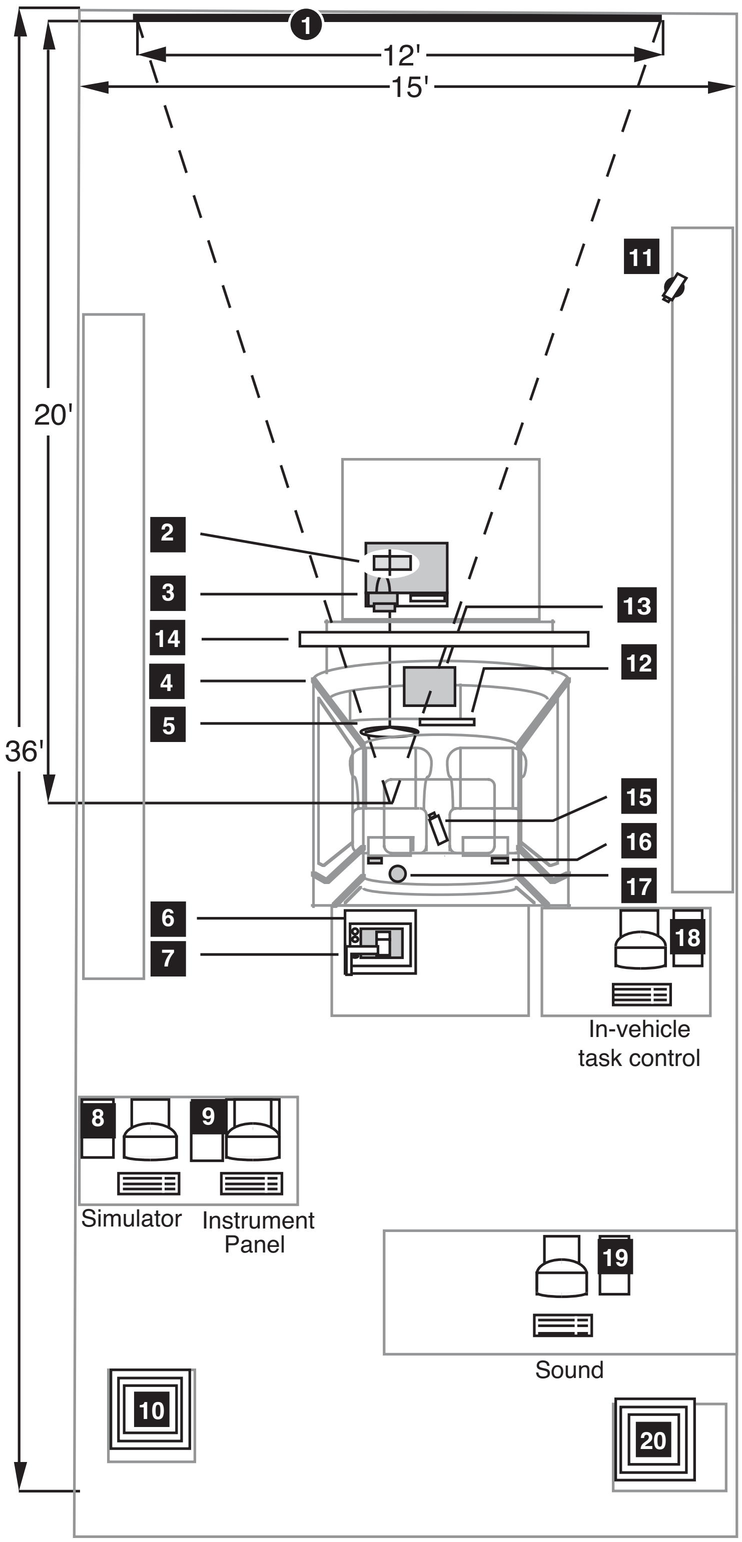
Table 4. Dependent and independent variables (including number of levels)

Dependent		Independent
Telephone number entry	Task completion time	*Part 1:*
	Number of errors by type	Age (2)
Driving performance: Lateral control	Lane departures (count)	Gender (2)
	Lateral Position (mean, SD)	Entry method (6)
	Yaw angle (mean, SD)	Display (3)
	Steering angle (SD)	
Longitudinal control	Headway (Mean, SD)	*Part 2:*
	Forward Velocity	Age (2)
	Accelerator Position	Gender (2)
Glance behavior	Total glance duration (mean, SD)	Entry method (6)
	Glance duration (mean, SD)	Driving workload (3)
	Time between glances (mean, SD)	
	Number of glances (mean, SD)	
Task partitioning behavior	Time between keystrokes (mean, SD)	
	Time between groups[clustering] (mean, SD)	
	Time within groups (mean, SD)	
Subjective rating	Rating of difficulty, workload, and safety	

Test Materials and Equipment

Driving Simulator

This experiment may be 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 (Figure 4) 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. The simulator will collect driving data at 30 samples per second.



1 8'X10' projection screen with 3M hi-white encapsulated reflective sheeting

2 PMI Motion Technologies ServoDisk DC motor (model 00-01602-002 type U16M4) with Copley Controls Corp. controller (model 413) and power supply (model 645)

3 Sharp color LCD projection system (model XG-E850U) for instrument panel

4 1985 Chrysler Laser mockup with simulated hood

5 3-spoke steering wheel with 2 push buttons center right

6 3M overhead projector (model 9550)

7 Sharp computer projection panel (model QA-1650)

8 Power Macintosh 9500/200

9 Macintosh 7100/80AV

10 Video rack

11 Panasonic low level light camera (model WV-BP510) with TV zoom lens (WV LZ 81)

12 Touch-screen (Elotouch 1225L)

13 Mitsubishi 15" flat panel LCD monitors (model LXA520W)

14 28.5" x 72" plexiglas screen

15 Panasonic low level light camera (model WV-BP550)

16 Sony speaker system (SR6-48)

17 Bass shaker

18 Power Macintosh 9500/120

19 Power Macintosh 9500/120

20 Audio rack

Figure 4. Existing simulator layout.

If construction is complete, the new UMTRI Driving Simulator may be used for this experiment. The platform is the KQ Technologies (formerly Hyperion) Vection driving simulator. The new simulator will provide for a much more realistic road scenes, a larger field of view, and a wider range of road geometries than the existing simulator. KQ Technologies of Ft. Collins, Colorado, is the primary vendor of mid-level simulators used by academia and automotive industry suppliers in the U.S. One drawback of the new simulator is that the screen to driver's eyes distance is somewhat less (15 feet versus 20 feet for the current simulator), an important feature when inside-outside accommodation is an issue.

The driving simulator consists of

(1) a full size vehicle cab with a touch screen center console, computer generated speedometer/tachometer cluster, operating foot controls, and torque motor to provide realistic force feedback. (This is the same cab as the current simulator, but a back end will be added.)

(2) three large screens (3 forward with a 120 degree field of 15 feet from the cab and 1 to the rear) to provide bright images to subjects. Each channel has a resolution of 1024x768 and updates at 60 Hz

(3) a tile-based architecture that allows for the creation of worlds consisting of a wide variety of expressways, residential, urban, rural, and industrial roads of 2 to 6 lanes with numerous types of intersections and expressway ramps. All roads comply with AASHTO and MUTCD standards. Day and night conditions can be simulated as well as fog. The figures that follow show two representative driving scenes

(4) a sound system that produces realistic engine, tire, and drive train sounds of the subject vehicle and traffic (including Doppler effects of passing vehicles), and cab vibration,

(5) a scenario development language that provides for mixed autonomous and scripted traffic. Traffic can be scripted to perform events at specific places or times as can traffic signals.

(6) the ability to record steering wheel angle, foot control position, speed lateral position, headway distance and time, and a host of other vehicle and world parameters in real time

(7) an eight-camera video system with channel selection to allow for quad split video and audio recording

Figure 5 shows some typical scenes.

Figure 5. Typical scenes in the new simulator

Simulated Roads

Two different types of simulated roads were designed for each experimental block. Specifically, the simulated roads were designed to impose varying levels of driving workload as the driver while the driver is dialing a phone number. As shown in Figure 6 from Tsimhoni and Green (1999) (see also Wooldridge, Bauer, Green, and Fitzpatrick, 2000), the visual demand increases linearly as the radius or curvature increases for curves of 3, 6, 9, and 12 degrees of curvature. In the current experiment, 3 types of road sections will be included. If the existing simulator is used they will be: (1) straight sections or slightly curved sections, (2) moderate curves [3 degrees of curvature, 582 m radius], and (3) sharp curves [9 degrees of curvature, 194 m radius]. All roads will be driven at a speed of 72.5 km/hr (45 mi/hr) without the aid of cruise control. At that speed, the driving simulator will provide about 10 seconds of preview to the driver.

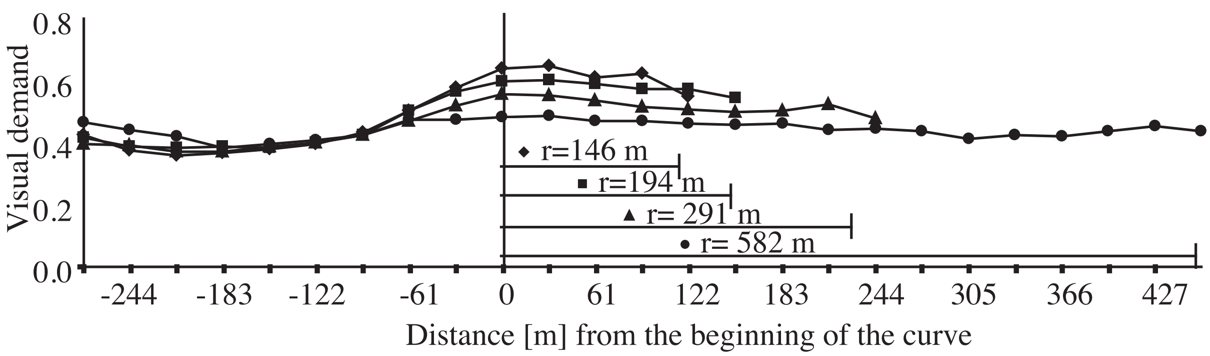


Figure 6. Visual demand as a function of curve radius and position.

Details of the workload for each section is still under review. There is concern that if the vehicle is to stable on the straight section, then the driver can line the car up and ignore steering for some time. For that reason slight curvature or a unsteady crosswind might be introduced. On most real roads, cars can remain in their lane for 5 or 6 seconds without driver intervention.

As was noted previously, the workload will be fixed for the first portion of the experiment and the road will essentially be straight. For planning purposes, the road was divided into timed sections where the dialing task will be completed on a straight section in 20 seconds or less. The tasks will then be separated by at least 30 seconds of straight or curved road (to provide subjects a break and allow for the collection of baseline driving data). The road was also designed to accommodate up to 15 trials in case the participant required additional practice at the beginning of the block. Three roads will be required for the first experiment to prevent the participants from memorizing the roads. The curved sections from the first road were randomized twice to create unique roads of equal difficulty. Finally, all three roads were duplicated and the trial time sections were lengthened (60 seconds) to accommodate for the longer dialing device configurations. Thus, a total of 6 roads were designed, where each unique road will appear twice and short roads will always be paired with short dialing tasks and long roads will always be paired with long dialing tasks.

The roads for the second portion of the experiment were designed following similar criteria. However, e levels of driving workload will be examined while the dialing tasks are performed. Therefore, equal lengths of straight sections, moderate curves, and sharp curves (curves were balanced in both directions) were randomized and distributed throughout the road. The duration of these test road sections were also 20 seconds, followed by a between road section of at least 30 seconds (comprised of straight sections and curves). Similar to the first portion of the experiment, the road was designed to accommodate up to 15 trials and three roads of equal difficulty will be required. Again, the first road was used as a template but the remaining 2 roads were created by (1) inverting the degree of curvature and curve direction of each curve in the original road, and (2) driving the original road backwards. Finally, all three roads were duplicated and the trial time sections were lengthened (60 seconds) to accommodate for the longer dialing device configurations. Thus, a total of 6 roads were designed, where each block will be performed on a different road. Again, short roads will always be paired with short dialing tasks and long roads will always be paired with long dialing tasks.

Both lanes of the two-lane road are 3.66 m (12 feet) wide. Traffic will consist of 5 vehicles: the participant's vehicle, a lead vehicle driving in the right lane, and 3 additional vehicles driving in the left lane. (See Figure 7.) The participant will be instructed to drive in the right lane at a comfortable distance behind the lead vehicle, which will maintain a constant speed of 72.5 km/hr (45 mi/hr). The left-lane lead vehicle will drive next to the lead vehicle at a variable speed from 71 km/h to 77 km/h (44 mi/hr to 48 mi/hr). The second left-lane vehicle will drive exactly 4 seconds behind it. The trailing vehicle in the left-lane will be a police car 5 seconds behind the lead vehicle, and the drivers will be instructed not to fall behind this vehicle. This particular traffic configuration was constructed to help keep the driver’s priority on the driving task. A typical view of the road, as seen by the participant, is shown in Figure 8.

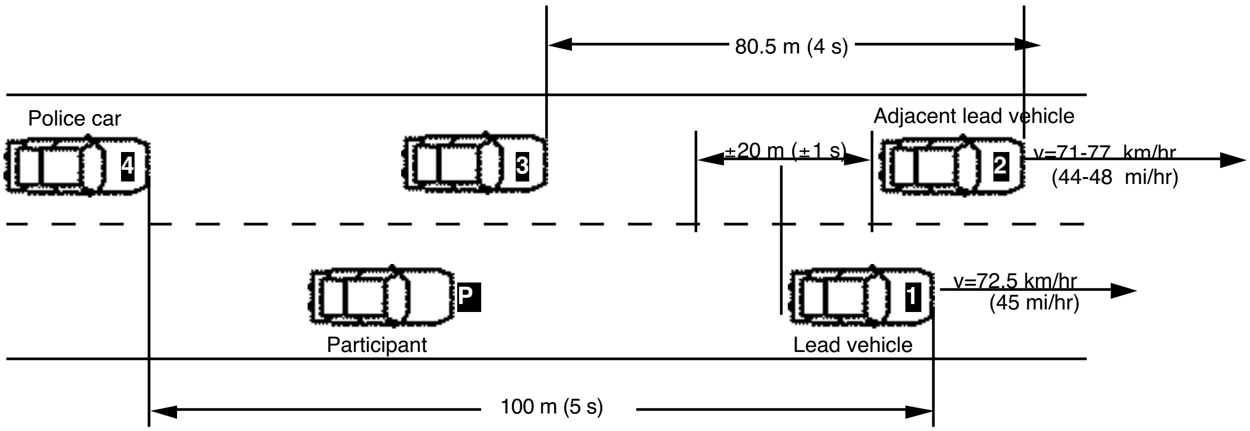


Figure 7. Typical traffic layout.

Figure 8. Typical simulator road scene.

Dialing Devices – 10-Key Keypad

A 10-key keypad was selected in this study to replicate the most commonly used dialing device. The number buttons on an Adesso Mini Keypad (model IKP-18) were relabeled to resemble a telephone configuration. Talk, end, and clear buttons were also added to the keypad to complete the functionality of the dialing device. Thus, the participant will dial a 10-digit number by pressing the desired numbered buttons and then pressing Talk upon completion. Subsequently, "Connecting…" will appear on the display. The clear button can be used to delete one number at a time and the end button will be pressed after finishing the task.

A USB port on the secondary task CPU was used to connect the computer with the keypad. Each key was 1.3 cm square and the entire keypad measured 9.5 cm wide by

11 cm high. The device was mounted on both the steering wheel and on the center console. Figure 10 on the following page summarizes the key measurements such as focal distance and visual angles for both device locations. An example of the 10-key keypad device can be seen in the following figure.

Figure 9. 10-key keypad in the center console location.

A competitive analysis showed other hard key keypad buttons (1.3 cm wide by 1.2 cm tall) were approximately the same size as the buttons used in this study. Fitt's law would also support that slightly larger keys will not greatly affect the dialing task performance.

<u>Dialing Devices – Joystick</u>

In addition to the traditional keypad, a 10-digit number can be dialed by manipulating a joystick controlled cursor and 4 auxiliary buttons. The cursor motion will be produced by an adapted Macally iShock II USB game controller 4 directional joystick in conjunction with a simulated display. Additional information about the display is provided in the Dialing Displays section. The display consists of an image of a 10 key telephone keypad with a cursor used to select the target digit. The subject will be instructed to highlight the desired digit by manipulating the cursor using the joystick in four directions and then depress the ok button to select the digit. The cursor will return to the 5 position (the center of the keypad) and the process will be repeated to select the next digit. When all 10 digits were entered, the talk button will be pressed and “Connecting…” will appear on the display. End and Clear buttons were also included in the joystick device design.

Originally, the game controller unit was equipped with two analog joysticks. The joysticks were separated from the casing and mounted on both the steering wheel spoke and on the center console. Both joysticks were connected though the controller to a USB port on the secondary task machine. Once again, Figure 10 on the following page summarizes the key location measurements. The joystick itself was 2 cm in diameter with a 3 cm stalk. The 4 auxiliary buttons (Talk, End, Ok, and Clear) are square pushbuttons, 1 cm on both sides. All parts were configured on an 6.5 cm square base. Figures 11 and 15 illustrate the joystick and its corresponding display.

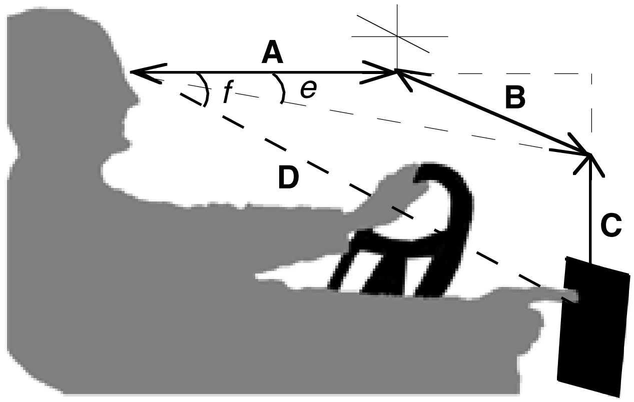
The joystick has been used as an input device for a number of navigation systems, including the Infiniti I30. With dashboard real estate at a premium, many manufacturers have used a single input device to control multiple in-vehicle systems such as navigation systems and cellular phones. Consequently, this type of device became the model for the dialing control for this study. While there are some differences between the joystick control used in the I30 such as shape and tactile feel, the underlying principles are the same, and the use of this joystick controller affords much greater ease of integration into the experiment and also ease of data collection.

Dialing Devices – Touch Screen

Finally, 10-key and cross-key dialing device configurations were modeled after the aforementioned hard devices. The simulated images will be displayed on an Elotouch 1225L flat monitor touch screen. The implementation of a 13-inch screen in the center console of a production vehicle was thought to be challenging and unlikely so the active area of the monitor was reduced to 16.5 cm wide by 12.5 cm tall using a black cardboard cover.

Functionality of the simulated devices will not differ from the real devices, although an enlarged size is necessary in order to compensate for the lack of tactile feedback and the nature of a touch screen. Thus, the 10-key touch pad graphic as drawn on the touch screen was 6.5 cm wide by 9 cm tall; each number key was 1.75 cm square. The cross key touch pad graphic included the directional keys (1.5 cm square) and the 4 auxiliary buttons (2 cm wide by 1.25 cm tall). A 20-sized font was used for all buttons. The average button size from several commercially available navigation systems was 1.0 cm square. The sizes of the dialing devices on the touch screen were in line with these systems with some allowance for the lack of sensitivity of the touch screen.

The following Figure 10 provides location measurements such as focal distance and visual angles for the devices in each possible location. Once again, the hard dialing devices will be mounted on the steering wheel spoke or the center console while the simulated devices appear on the touch screen. Because the multifaceted touch screen will also be used to show the device display, the center of the touch screen was used to obtain measurements B and C. However, the devices and displays are not located in the center. Thus correction measurements and detailed images of the touch screen and the various devices and/or displays possibilities can be found in Figure 11. Each image was reduced by 40%, where the original area was 16.5 cm wide by 12.5 cm high. The 10 key keypad display was not represented; however, it was located in the same position as the white box in Figure 11 (b).



	Measure	Touch Screen	Steering Wheel	Center Console	Memo Display
A	(cm)	58-70	38-50	58-70	27-39
B	(cm)	34	13	30	48
C	(cm)	30	14	27	33
D	Focal Distance (cm)	73-83	43-53	70-80	65-70
e	Angle Right of Center	28±2	16±2	26±2	29±2
f	Angle of Declination	25±2	18±2	23±2	56±2

Figure 10. Location summary for the touch screen, wheel, center console, and memo.

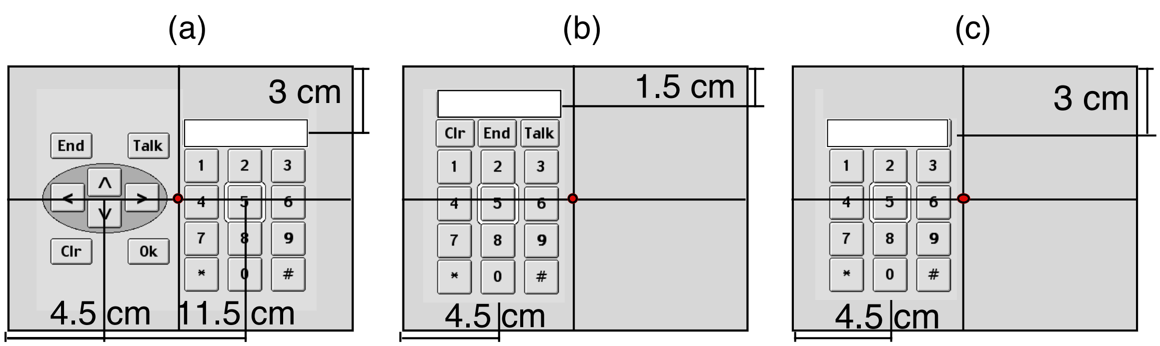


Figure 11. Correction measurements for (a) cross key touch pad and display, (b) 10 key touch pad and display, and (c) joystick display.

Dialing Devices – Remote

The remote hand held dialing device will be designed to emulate some of the remote devices which have become popular in the Japanese domestic market but have yet to penetrate the American market. The remote dialing device in this study will be a hand held 10 key keypad. The thickness of the keypad will be approximately the same as that for other in vehicle remote controls. The integration of the remote dialing device is still being resolved due to development of communication protocols between the remote and the secondary task computer.

Device Displays –Touch screen

The touch screen will be used to show each device's corresponding display image. The 10-key keypad required only a small box (6.5 cm wide by 1.25 cm tall) where the numbers will appear as they are dialed. Alternatively, the joystick required an interactive display consisting of a telephone keypad image and cursor. The keypad was the same size as the previously mentioned 10-key touch pad. The cursor will indicate the location of the active number and can be moved by pushing the joystick in one of four directions. Once the desired number becomes active, it will be selected by pressing Ok. The number will then appear in a 6.5 cm wide by 1.25 cm tall box above the keypad image. Figure 12 below illustrates the joystick device and its corresponding touch screen display.

Figure 12. Joystick and its corresponding touch screen display.

Device Displays – Head up Display

The simulated HUD will consist of a Mitsubishi model LXA520 W LCD color display flat panel monitor which will project images onto an acrylic sheet (hung slightly in front of the where the windshield would be located). As shown in Figure 13, the participants will see these reflections superimposed on the road scene. The images will appear at a focal distance of between 80 and 100 cm (31.5 and 39.5 inches) from the participant's eyes. The horizontal angle between the HUD Locations will be fixed for an average viewing distance of 90 cm (35.4 in). Thus, taller drivers will see the images between .5 and 1.5 degrees closer to center and shorter drivers will see the images between .5 and 1.5 degree further from center. The vertical location of the

HUD images will be adjusted for seating height only enough to keep the image background on the road about 1 character height above the hood of the car.

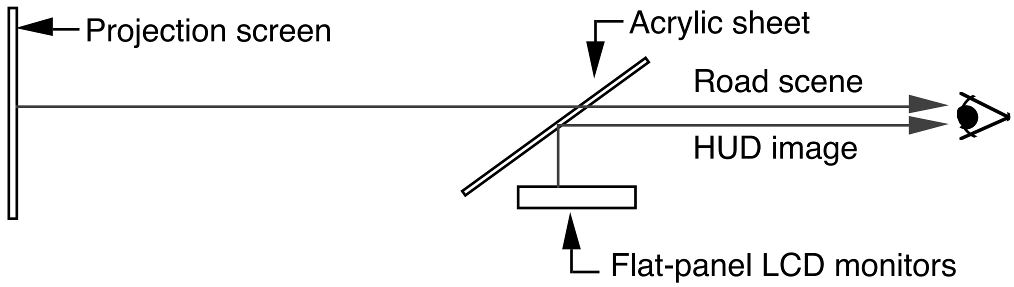


Figure 13. Diagram of the simulated HUD.

The HUD display will interact with the real devices in the same manner as the touch screen display. When the keypad is used, the 10-digit number will appear on the HUD one number at a time. When the joystick is used, the telephone keypad and cursor will be projected onto the HUD. Al of the characters are 50 point Helvetica. The HUD telephone keypad and number were displayed in monochrome green (RGB value of R=94, G=226, B=81) while the cursor was yellow (RGB value of R=256, G=256, B=128). The following figure shows the HUD image when used in conjunction with the joystick.

Figure 14. Joystick device on the steering wheel and its HUD display.

Phone Number Presentation

The ten digit phone numbers will appear on a memo-display (5-inch diagonal TFT AM-064P Advanced Video and Communication Inc.) located to the right of the driver at arm's length. The memo display will simulate a low-cost address book or a piece of paper on which phone numbers may appear. Characters on the display were relatively large (0.017 radians, 57 arc min) to allow for easy reading. The memo will be positioned to allow the experimenter to distinguish between looks to the memo display and looks to the touch-screen keyboard. The exact location measurements including focal distance and visual angles were given in the above Figure 10. An audible method will also be used to alert the participants to begin the next trial. The ten-digit number will be announced by a computer-generated voice at the same moment the phone number is presented on the memo.

Phone Number Selection

Phone numbers for this study were selected using the following multi-step process. The intent was to take into consideration the fact that certain sequences of phone numbers were more common then others and the numbers were not random.

1. The white pages in the Ann Arbor, MI Ameritech Phone book for 2001 (containing 482 pages) was used to select 100 names. One name was selected from every 4th page.
2. There were three columns and the column number was rotated, the first, fourth, seventh numbers from the first column, the second, fifth and eight number from the second column and so on.
3. A random number was generated between 1 and 75. This determined the position in the column from which a name was taken.
4. A name was selected from each column. The names were entered into Yahoo's people search (http://people.yahoo.com/) and the first non-local phone number was selected.

Test Activities and their sequence

Following a brief introduction to the study, the participants will be asked to sign a consent form, complete a pre test survey, and perform a brief far visual acuity test. Next, the participant will familiarize themselves with the simulated vehicle and practice driving for 8 minutes on a road that will consist of straight sections, moderate curves and sharp curves. Baseline data will be collected during the last 4 minutes of the road.

The first portion of the experiment will be performed in 6 test blocks where a straight road will be combined with 6 different dialing device/location configurations. Presentation of the test blocks will be randomized over all 24 participants. The number of trials within each block will be dependent on the number of displays that varied per block. (See Table 5 for clarification). For each trial, the participant will be asked to view a 10-digit number from a small display monitor (mounted next to the participant) and then dial the number using the dialing device configuration and specified display. Timing will commence when the number is displayed on the memo (and announced audibly) and stop when the end button is pressed. The dialing device and its location will be fixed for each block. Test block one will be set up and the participant will be able to practice before data collection began for the remaining trials. All test trials will occur on a straight section (0 degrees of curvature) or slightly curved road. In the same manner, the next 5 test blocks will be set up and consecutively run before the participant is given a short break.

Table 5. Test Activities Summary

Block	Device	Location	Display	Degree of Curvature	Test Trials	Duration (min)
A	*Introduction, pre test survey, vision test*					*10*
B	*Baseline driving*					*8*
1	10 Key	Wheel	(CC,None)	0	8	10
2	10 Key	CC	(HUD,CC)	0	8	10
3	Joystick	Wheel	(HUD,CC)	0	8	14
4	Joystick	CC	(HUD,CC)	0	8	14
5	10 Key	Remote	(HUD,Remote)	0	8	10
6	Touch screen	CC	(10 Key)	0	4	10
7	10 Key	Wheel	HUD	(0,3,9)	12	11
8	Touch screen	CC	Cross Key	(0,3,9)	12	23
9	Joystick	CC	CC	(0,3,9)	12	16
C	*Post test survey, payment*					*5*

Following the completion of the first six blocks, the second portion of the experiment will run in an identical manner, however, the display will not change for each of the three test blocks. Instead, equal repetitions of trials will occur on road sections with varying degrees of curvature. Finally, the participants will complete a post test survey and then be compensated for their time.

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APPENDIX A. CONSENT FORM

Date: ____________ Participant number: ___________

Telephone Number Entry using Manual Methods

Investigators: Kenneth Mayer and Paul Green (763 3795)

The purpose of this study is to assess the safety and usability of a couple of methods for entering complex data in moving vehicles. You will drive the simulator while entering telephone number to a computer using a keypad, a joystick or a touch screen keyboard.

First, you will practice driving the simulator. There is a small risk of some motion discomfort while driving the simulator. If you feel discomfort of any significance, please let the experimenter know, so the study can be stopped. After the driving practice, you will practice entering telephone numbers while parked and then you will enter telephone numbers several times while driving. Audible numbers will be provided and shown on the monitor to your right.

For some drivers, these tasks are quite difficult. Regardless of the difficulty, it is important to try to do your best on both tasks.

Your driving will be videotaped for future reference to your data entry performance, driving performance, and reactions overall. This study is not intended to be a test of your skill, but rather how well the system has been designed to suit you.

The study should take about two and a half hours, with a five-minute break scheduled in the middle. You will be paid $35 for your time. You can withdraw from this study at any time without penalty.

I specifically agree to be videotaped in this study and understand that (1) a copy may be provided to the sponsor and (2) selected segments from the tapes may be used in presentations to explain the results. The raw tapes will be erased 10 years after the project is completed.

Sign your name ________________________

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

________________________ Print your name	________________________ Date
________________________ Sign your name	________________________ Witness (experimenter)

APPENDIX B. BIOGRAPHICAL FORM

Date:_______ Participant number: _______

Telephone Number Entry Using Manual Methods – Bio Form

Personal Details

Name ___________________________

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

Handedness (circle one) left right

Phone: __________________________

Email address ________________________

- May we email you for future studies? Yes no

Education

(circle highest level completed, fill in blank)

high school

some college/major :_________________

college degree :_________________

graduate school: major _______________

Occupation: ________________

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

Driving

What motor vehicle do you drive most often?

Year: _________________ Make: _______________ Model: _______________

How many miles do you drive per year? ____________

How much time do you spend on an average day driving (not as a passenger?)

__________ hours

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

No Yes: explain -> _________________

How many accidents have you been involved in during the past 5 years? _____

How many tickets for moving violations have you had in the last 5 years? _____

On an expressway with 3 lanes on each side, in which lane do you normally drive?

Left middle right

Cellular Telephone Use
Do you own a cellular telephone? Yes No
If Yes, how many calls do you make per week? _________
Have you ever used a cellular telephone while driving? Yes No
How often do you use a cellular telephone while driving?
Once in a while Once a week Once a day Constantly

Typing Skills
How many hours a day do you type on a keyboard? __________
At what age did you learn typing? ___________

Vision Circle what vision correction you use
When driving: no-correction contacts glasses (multifocal, bifocal, reading, far-vision)
When reading: no-correction contacts glasses (multifocal, bifocal, reading, far-vision)

For the experimenter only
12526616

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

	Keyboard	TouchScreen
Typing speed:	___________	___________
Typing Accuracy:	___________	___________

Comments:

APPENDIX C. POST-TEST EVALUATION FORM

Date: ________ Participant number: ________

Post-test Evaluation Form

Please fill numbers (from 1 to 10) in the highlighted boxes according to the instructions

(1=strongly disagree, 10=strongly agree)
(1=extremely easy, 10=extremely difficult)

***Difficulty**: (read all 3 questions first)*	Keypad	Joystick	Touch Screen
1. It was difficult to enter telephone numbers while parked			
2. It was difficult to enter telephone numbers while driving			
3. It was difficult to drive while dialing telephone numbers			

(1=strongly disagree, 10=strongly agree)

***Safety**:*	Keypad	Joystick	Touch screen
4. It is unsafe for me to enter telephone numbers while driving			
5. It is unsafe for older drivers to enter telephone numbers while driving			
6. It is unsafe for older drivers to enter telephone numbers while driving			
7. In general, drivers should not be allowed to telephone numbers while they drive			

(1=strongly disagree, 10=strongly agree)

General:	Keypad	Joystick	Touch screen
8. If this system was installed in my car I would consider using it while driving			
9. If this system was installed in my car I would consider using it while parked			
Explain:			

Comments about this study? (Please think of at least 2…)

APPENDIX D. MODIFIED COOPER HARPER WITH VACP

1. Please rate the overall difficulty of this task

1 2 3 4 5 6 7 8 9 10

2. Please rate the difficulty of the driving task for this trial

1 2 3 4 5 6 7 8 9 10

3. Please rate the difficulty of the [secondary task] for this trial

1 2 3 4 5 6 7 8 9 10

4. 4.Please describe the workload of the [secondary task] for each of the following components

Visual	1	2	3	4	5	6	7	8	9	10
Auditory	1	2	3	4	5	6	7	8	9	10
Cognitive	1	2	3	4	5	6	7	8	9	10
Manual	1	2	3	4	5	6	7	8	9	10
Speech	1	2	3	4	5	6	7	8	9	10

5. Do you feel this task is safe for you to perform while driving?

APPENDIX E. SAMPLE TEXT FOR TYPING TEST

This sample text was given to test typing speed in a 1-minute interval. The text consists of 100 words with 4.1 mean characters per word and a Flesch-Kincaid grade level of 7.7

> The famous sea explorer James Cook was born on 28 October 1728 in a village in Yorkshire in England. He was the son of a poor Scottish farmer and thus was very unlikely to have seen many books before going to school. There he is said to have been very good at arithmetic.
> At the age of twelve James left his home in order to learn some shopkeeper's trade in a fishing village. That must have been quite a change in the young boy's life as he had probably never left his home village before. On his way to the