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Display of Short Text Messages on Automotive HUDs: Effects of Driving Workload and Message Location

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HUMAN FACTORS

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16. Abstract

This report describes the second in a series of studies to identify best locations for presenting various types of information on a head-up display (HUD). In the current study, 16 subjects drove a simulator on roads with curves of several different radii while responding to messages appearing at one of 8 locations on a HUD. Two types of information were presented on the HUD in separate conditions. In the naming condition, subjects indicated the gender (male, female) of a first name shown on the HUD. In the detection condition, garbled names were presented, to which subjects had to respond upon detection. Response time to messages increased with the horizontal eccentricity of the HUD location. The center positions (straight ahead) had mean response times of 1100 ms, whereas the outer positions (10 degrees to either side) had mean response times of 1250 ms. In contrast to reading time, detection time was not significantly affected by where the message appeared. Driving performance was only degraded when the HUD appeared at the center position. The most preferred position was 5 degrees to the right of the center, at eye level. Increasing driving workload significantly increased detection time and as a result increased response time to reading the messages. In agreement with the slower response times, more HUD messages were missed while driving on sharper curves. Overall, the driving performance of older men was less variable than other age-gender groups. However, their responses to HUD messages were slower and they committed more errors.

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Display of Short Text Messages on Automotive HUDs: Effects of Workload and Location on Driving

UMTRI Technical Report 00-13
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ISSUES

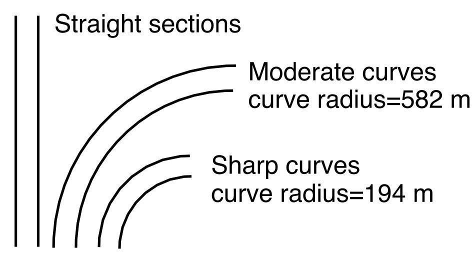
1. What is the effect of HUD message position on response time to messages (and errors), on concurrent driving performance, and on driver subjective preference?
2. What is the effect of driving workload on response time to messages and on concurrent driving performance as a function of message location?
3. How do driver age and gender affect performance?
4. How do drivers tradeoff their performance in the driving (primary) and response time (secondary) tasks?

TEST PLAN

16 Subjects

	Female	Male
Young (21-30)	4	4
Old (over 65)	4	4

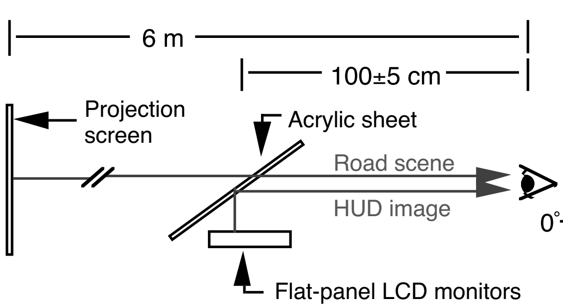
3 Driving Workload Levels



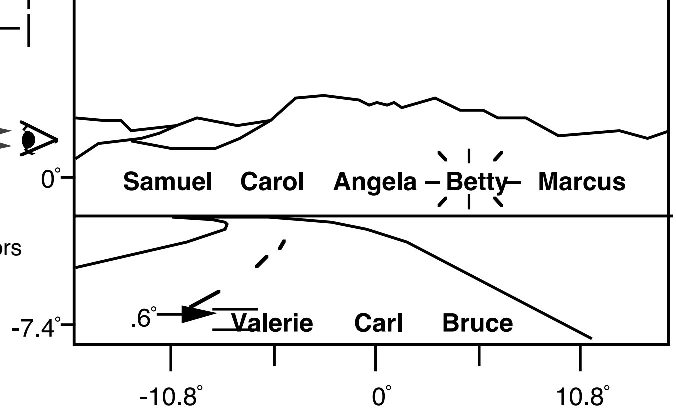
2 Task Types

Detection: As soon as a scrambled word appears on the HUD - press the finger mounted switch (only one mounted)

Naming: As soon as a name appears on the HUD - read it, determine if it is male or female, and respond by pressing one of two finger mounted switches



8 HUD Positions (only 1 visible)



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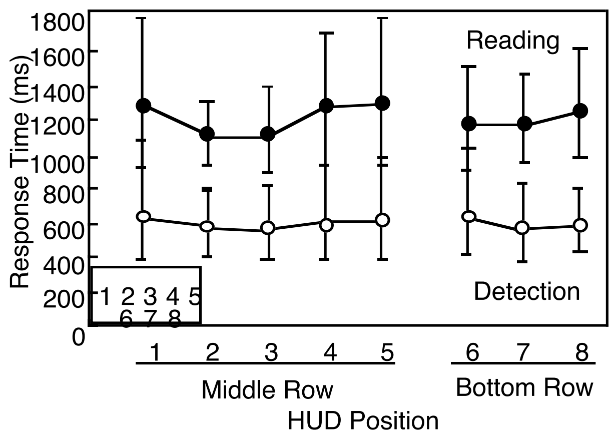
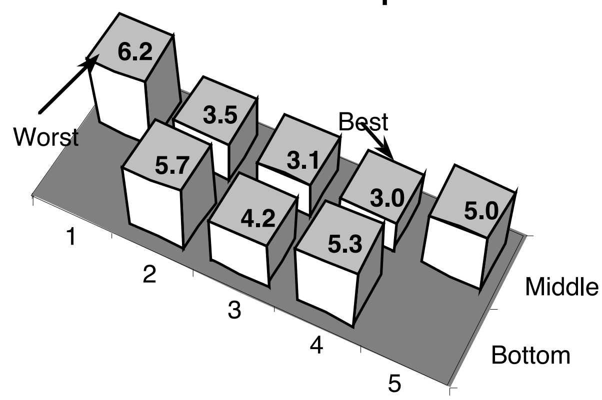
RESULTS

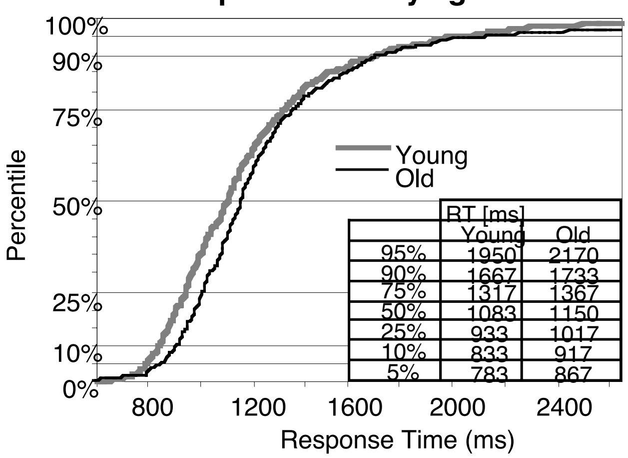
Response time by HUD position



Preference for HUD position

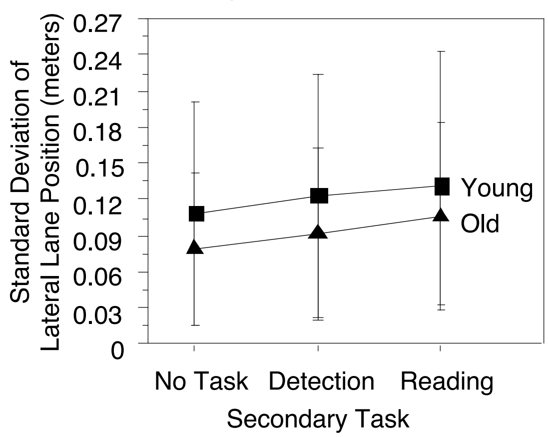


Response time by age

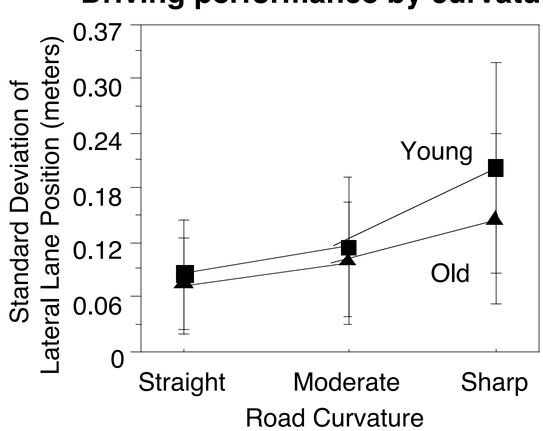


	RT [ms]	
	Young	Old
95%	1950	2170
90%	1667	1733
75%	1317	1367
50%	1083	1150
25%	933	1017
10%	833	917
5%	783	867

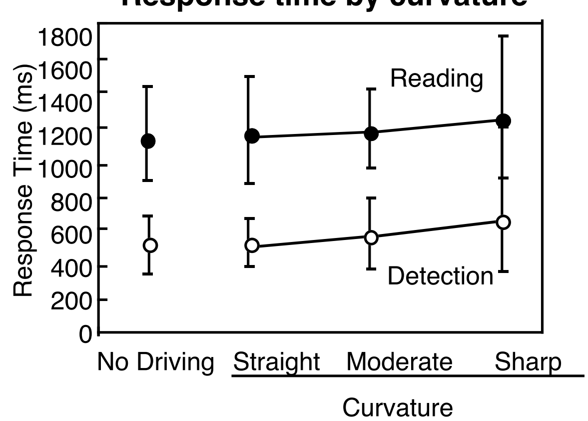
Driving performance by task



Driving performance by curvature



Response time by curvature



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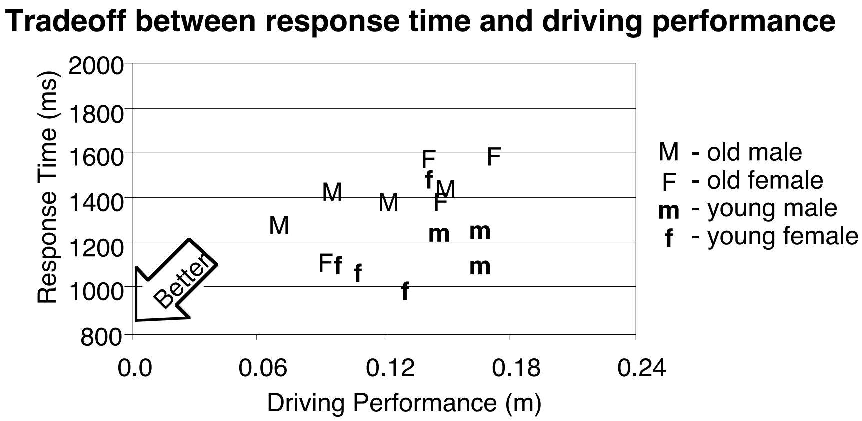
RESULTS (CONTINUED)



4 CONCLUSIONS

Overall, the central location and other locations within 5 degrees of straight ahead gave the best performance and were more likely to be preferred, followed by the other two locations on the bottom row. The particular location that is best for a specific application depends upon the relative importance attributed by designers to the measures collected.

Response times to names at the center were faster (1100 ms) than at outer positions (1250 ms), but detection times were not affected by this eccentricity effect.

Driving performance was only degraded when the HUD appeared at the center position.

Subject prefered the center positions of the middle row better than the outer positions or the bottom row.

Sharper curves significantly increased detection time, but there was no additional increase for response time to names.

On sharp curves, more HUD messages were missed, but there were not more errors of pressing the wrong switch.

Driving performance was degraded on sharp cuves. The effect of driving workload on driving performance was larger for younger subjects

Subjects reported that performing the HUD task was more difficult on sharper curves.

Old subjects typically performed worse than younger subjects on the HUD task but their driving performance was better

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INTRODUCTION

Over the last few years there has been a proliferation of in-vehicle systems and functions. Climate control systems provide for temperature control for individual occupants. Entertainment systems allow for switching among multiple CDs. Navigation systems, often complex as all previously existing interior features, have been added. Thus, drivers are now faced with operating an increasingly complex vehicle and future projections are for greater increases in complexity. However, drivers are not becoming more capable at operating these systems and the demands of driving, due to growing congestion, are presenting greater challenges as well.

For a variety of reasons, much of this new information can be processed most rapidly by drivers when the information is presented visually. However, the driver's visual channel is sometimes very heavily loaded, and switching between the exterior scene and in-vehicle displays can degrade driving. One potential solution is to present some of the information than might appear on an in-vehicle display (for example, on a center console display) on a head-up display (HUD) instead. Providing information on a HUD minimizes eye travel time to and from the road and allows for the detection of critical events in peripheral or unaccommodated vision.

Where information should be presented, either inside the vehicle or on a HUD, depends on the priority associated with it, the required display area, the display area available, the need to share information with passengers, and other considerations. Message priority has been the topic of considerable discussion in recent meetings of International Standards Organization, Technical Committee 22, Subcommittee 13/ Working Group 8 (ISO TC 22/SC 13/WG8, Ergonomics of Road Vehicles-Transport, Information and Controls Systems). The focus of the discussion on message priority has been on the number of dimensions that should be used to prioritize messages, primarily warning messages. Document ISO/TC 22/SC 13/WG8/N244, based on Japanese input, proposes there are 2 primary dimensions, criticality (the injury consequences of failing to act) and urgency (how soon one must respond). There has also been discussion of a third dimension that examines the likelihood that injury might occur. Tables 1 and 2 show the criticality rating scales from document N244. The aggregate message priority is determined by adding the two ratings.

Table 1 - ISO criticality rating scale

Rating	Occupant injury	Vehicle damage	Example crash scenarios
3	Serious or fatal	Badly damaged	Collision at high speed. Leaving the roadway, head on collision and collision with structures at intermediate speed.
2	Injury and possibly injury	Slight to moderate damage	Vehicle (side) to Vehicle (side) collision at intermediate or low speed, leaving the road, head on collision or collision with structures at intermediate or low speed.
1	None	Slightly damaged	Vehicle to vehicle collision (except head on collision) at low speed.
0	None	No damage	Vehicle to vehicle contact at very low speed.

Table 2- ISO urgency rating scale

Rating	Description	Example crash scenarios
3	Respond immediately Take an immediate action according to the displayed indication.	Obstruction immediately in the vehicle path. Slam the brake immediately. Steer to avoid dangerous situations
2	Respond within a few seconds Take an action according to the indication within a few seconds.	Obstruction within few seconds in the vehicle path. Slam the brake in a few seconds. Steer away from danger as required.
1	Prepare to respond Prior warning for preparation to take an action according to the indication within a few seconds to a few minutes	Onset of detection of an obstacle.
0	Information only Indication to show only information about a situation without need of taking action to the situation	Notification that the system is on

While criticality and urgency might be most important for warning messages, several other criteria should be considered when assessing the priority of messages commonly associated with ordinary driving tasks. For those messages several measures should be considered: (a) the importance of the message to the driving task, (b) the safety consequences to the vehicle and the driver if the information is not read, (c) the immediacy of the required response, (d) the frequency of occurrence or the desired frequency of use of each message, and (e) the possible interference with driving of attending to the message. For messages that are not directly related to the driving task, several more measures should be considered: (e) the desire of the driver to have access to nondriving messages (e.g., cell phone call), and (f) the possible safety advantages of such messages (e.g., listening to the radio might raise the driver's arousal while sleepy). Figure 1 shows how such a scheme might be used to classify information displays related to driving using two of these dimensions, (a) and (d).

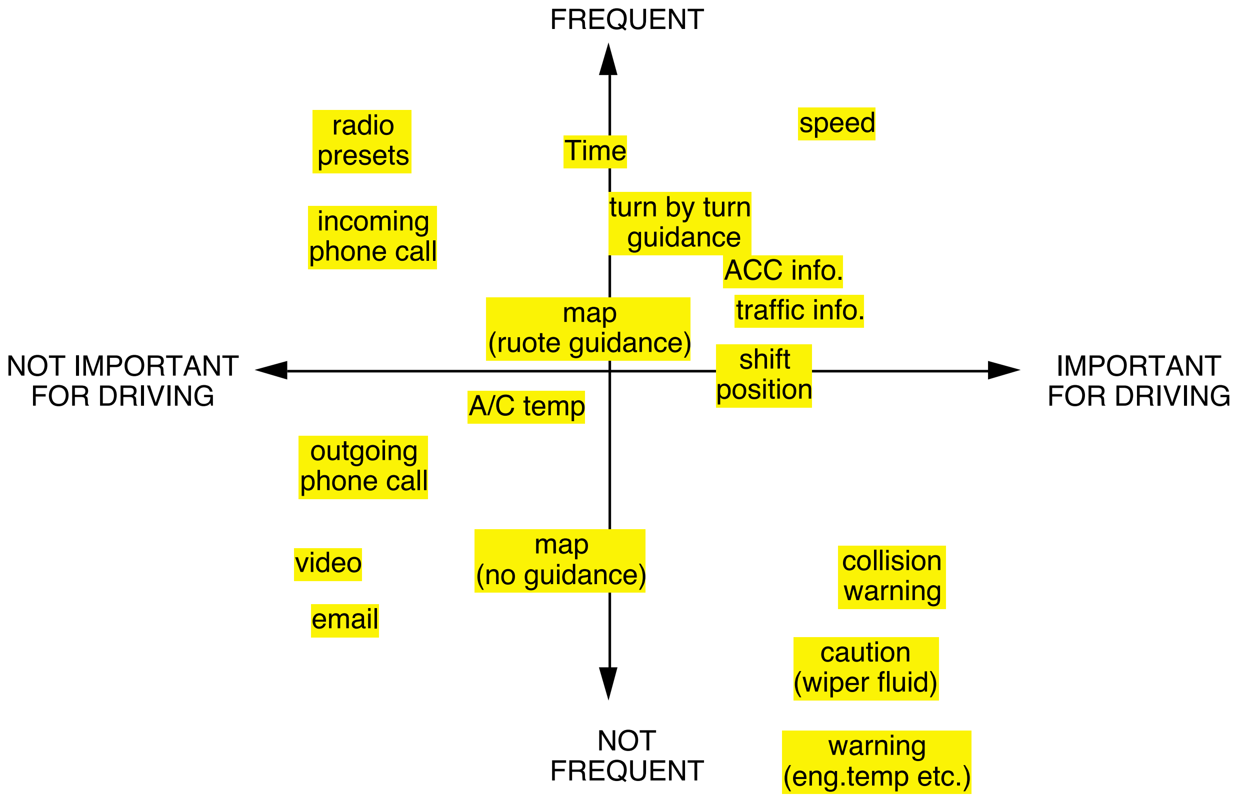


Figure 1. Classification of displays by importance and frequency of use

Competition for instrument panel and HUD "real estate" is intense, and prioritization schemes such as these can accelerate design and by reducing contention, improve design team harmony. Figure 2 is another example of classifying information displays using importance and immediacy. Messages that are important and need immediate response are high priority items for HUD real estate.

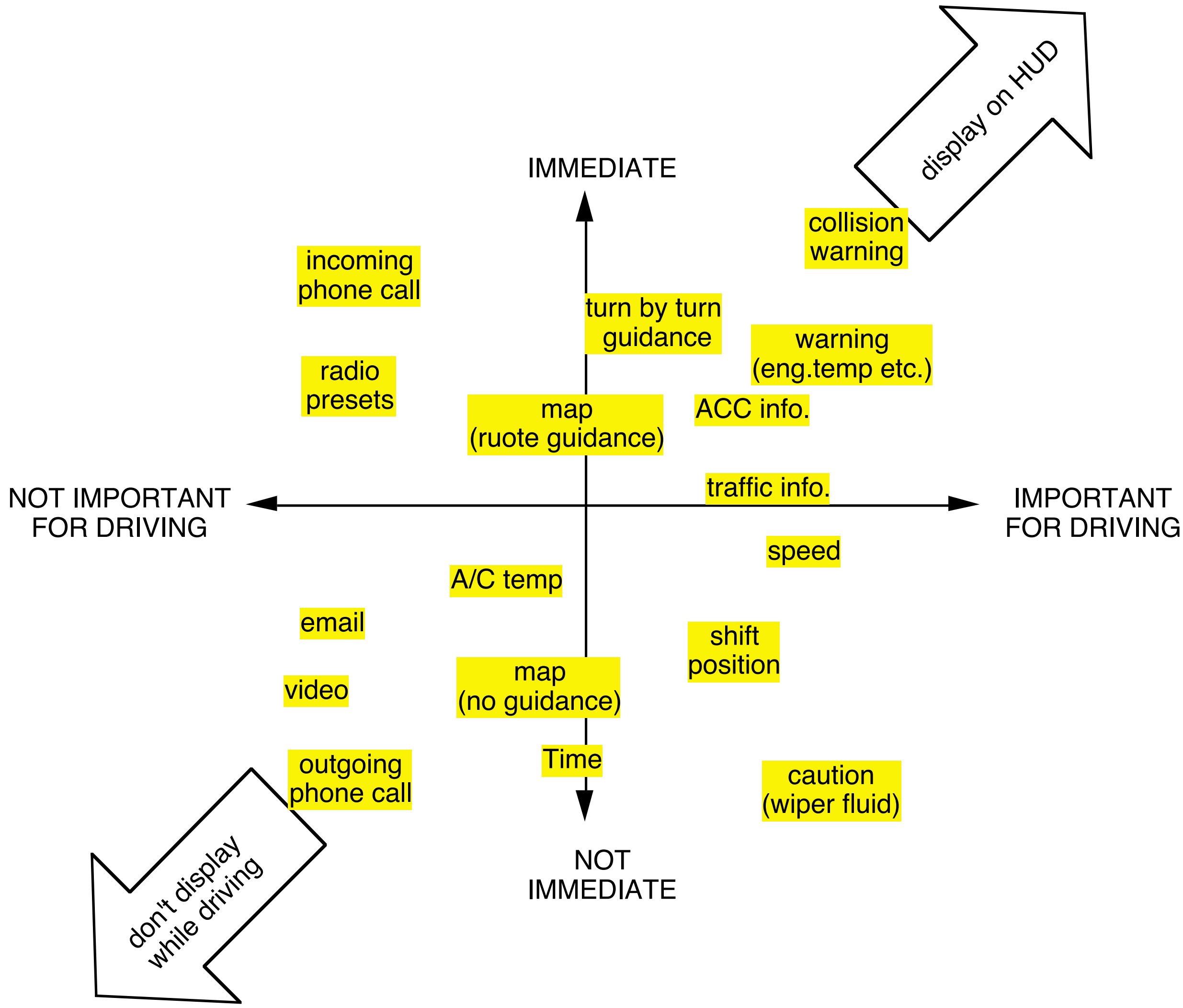


Figure 2. classification of displayed information by importance and immediacy

Because of its frequency of use and potential safety implications, the use of a HUD to display phone-related information is of particular importance. Desired is the display of phone numbers for outgoing calls as they are entered (to reduce errors) and of incoming callers (caller ID) to provide selectivity and potentially reduce interference with driving.

Given the potential performance advantages of HUDs and safety implications, experimental validation is required. Considerable research has been conducted to examine driver use of HUDs, research that is summarized in the previous report in this series (Yoo, Tsimhoni, Watanabe, Green, and Shah, 1999). A careful review of the literature revealed that the effects of location had not been examined systematically.

To overcome that deficiency, Yoo, Tsimhoni, Watanabe, Green, and Shah had 24 subjects sit in a driving simulator and watch a video tape of a real expressway. To encourage subjects to scan the scene as they would while driving, subjects pressed a button when various events occurred (the brake lights of the lead vehicle illuminated, certain types of signs were visible, etc.). At random times, triangles intended to represent a generic hazard warning were presented at any one of 15 locations (3 rows of 5 columns) on a HUD. The matrix of those locations spanned the central 20 degrees wide by 10 degrees high center of the field of view.

The mean response times varied from approximately 840 to 1390 ms, with the fastest response time occurring 5 degrees to the right of center. The detection probability of 12 of the 15 locations within a 5 s response time window was 0.97. Response times to road events (lead vehicle's brake lights, etc.) increased by 7 percent (from 1175 to 1260 ms) when the HUD task was added, a nonsignificant difference. In general, subjects preferred the location 5 degrees to the right of the center, so it is the recommended location for HUD warnings, though the equivalent location to the left of center is also suitable.

The study reported here extends the prior research to consider the relationship between HUD information location and more complex tasks, namely reading, and examine the effect of workload. A detection task was included in this experiment for two purposes: (1) to provide a within-subject comparison between detection and reading and (2) to provide a bridge to the prior experiment (Yoo, Tsimhoni, Watanabe, Green, and Shah). The primary difference between detection and reading was the additional required processing of the displayed information, which should lead to a constant difference between reading time and detection time as a function of eccentricity. However, if detection is peripheral, then the addition of an eye fixation in the reading task should lead to an interaction with eccentricity.

When studying the driving performance, it is important to include subjects that represent the driver population. In the current study, two age groups (20 - 30 and over 65) participated. These two age groups represent two extreme segments of the driving population in terms of performance, with the older segment growing as a percentage of the population. See Table 3 for details about the projected growth in the general old population in Japan and the United States.

Table 3. Projected population growth of older people in Japan and the United States

	Over 65 years old		65-74	
	1998	2020	1998	2020
Country	Million (%)	Million (%)	Million (%)	Million (%)
Japan [1,2]	20 (16.2%)	33 (26.8%)	12 (9.8%)	
United States [3,4]	34 (12.5%)	47 (16.5%)	18 (6.6%)	29 (10%)

Sources:
1. National Institute of Population and Social Security Research, 1999
2. Statistics Bureau, Management and Coordination Agency, 1999
3. US DOT, 1999
4. US Census Bureau, 1999

Specifically, the following questions were addressed with regard to short text messages presented on a HUD:

1. What is the effect of HUD message position on response time (and errors) to messages, on concurrent driving performance, and on driver subjective preference?

   Both detection tasks and reading tasks were examined. Response times were measured from the time the message appeared on the HUD until the finger-switch was pressed by the subject. Errors include not detecting a message and pressing the wrong key in the reading task. Driving performance measures examined include the standard deviation of lateral position and the standard deviation of steering wheel angle.

2. What is the effect of driving workload on response time to messages and on concurrent driving performance as a function of message location?

   Performance should degrade as workload increases.

3. How do driver age and gender affect performance?

   Generally large differences due to age are found and interactions between age and gender.

4. How did drivers tradeoff performance in the driving (primary) and response time (secondary) tasks?

   One of the major challenges in driving studies is that individuals will give different emphasis to the collection of tasks, making comparisons across individuals a challenge. Further, sometimes individuals change how they behave within an experiment, for example minimizing response time in one condition, errors in another. Careful control of test conditions should allow for identification of some of these tradeoffs.

TEST PLAN

Overview

Subjects drove a simulator on roads with curves of several different radii while responding to messages appearing at one of 8 locations on a HUD. Two types of information were presented on the HUD in separate conditions. In the naming condition, subjects indicated the gender (male, female) of a first name shown on the HUD by pressing 1 of 2 finger-switches positioned on their right and left index fingers. In the detection condition, garbled names were presented, to which subjects had to respond by pressing the right finger-switch as soon as they recognized that anything had appeared on the HUD.

Test Participants

Sixteen licensed drivers participated in this experiment, 8 younger (22-27 years old, mean of 23) and 8 older (65-71 years old, mean of 68). In each age bracket there were 4 men and 4 women. Participants were recruited via an advertisement in the local newspaper, and from the UMTRI subject database. All were paid $35 for their participation. Table 4 summarizes some characteristics of the subjects. They reported driving 2,500 to 25,000 miles per year (mean of 11,800). (The average mileage reported by U.S. drivers is about 13,000 miles per year: 14,600 for young drivers of 20-29 years and 7,500 for drivers older than 60 [http://www.fhwa.dot.gov/ohim/hs97/nptsdata.htm].

Subjects were tested for far and near visual acuity, depth perception, peripheral vision, and color vision. All subjects had far visual acuity of 20/40 or better as required by Michigan State law. However, more than half of the older subjects had near vision acuity worse than 20/40 (measured with a 1 diopter lens to simulate a reading distance of 1 m). Most subjects had a stereo depth perception of at least 100 s of arc in angle of stereopsis. All subjects had a peripheral vision range of 125 degrees at the minimum. None of the subjects had color deficiency.

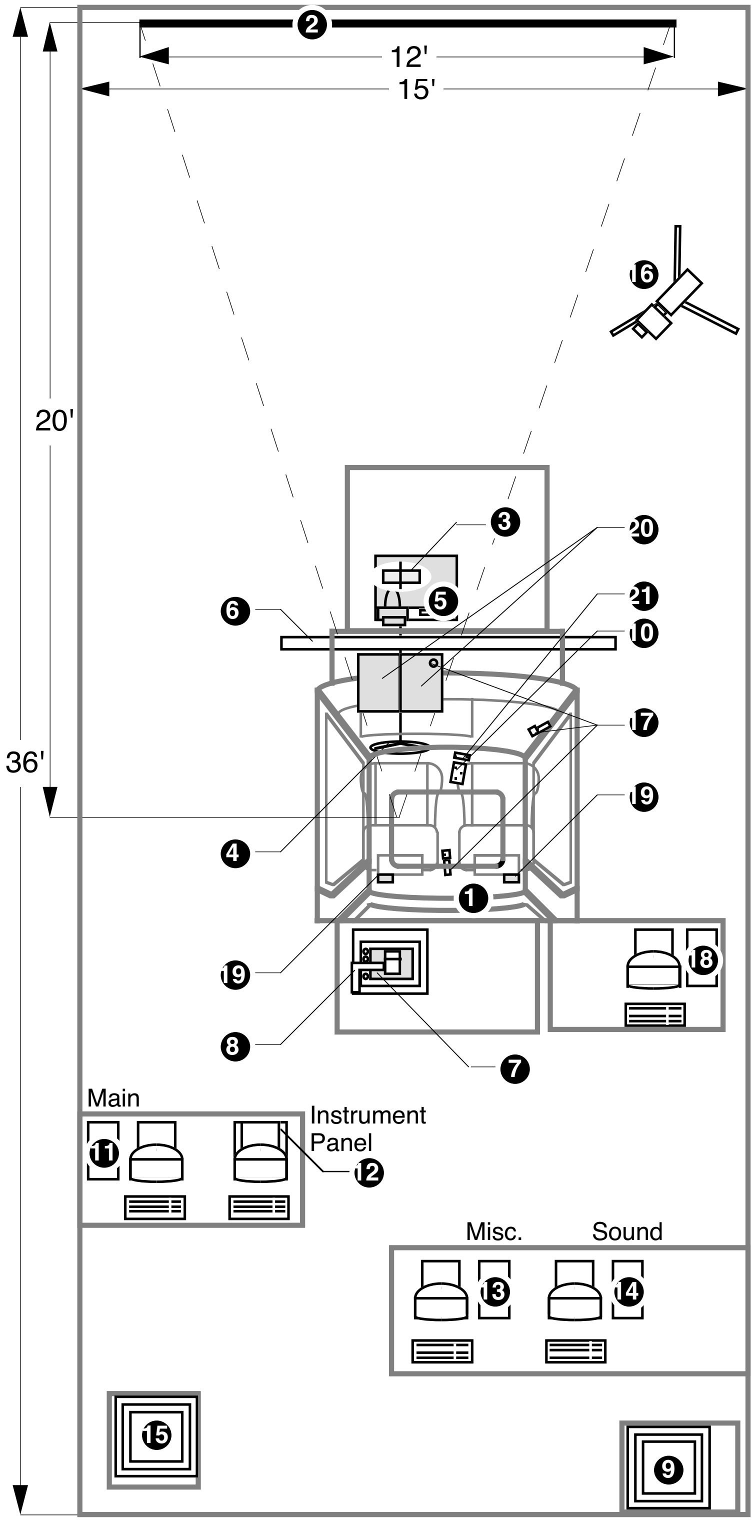
Table 4. Subject information

	Young		Old		Young	Old
	Female (4)	Male (4)	Female (4)	Male (4)	(8)	(8)
Mean age	24	23	68	68	23	68
Mean years of driving	7	7	49	52	7	51
Mean annual mileage	8500	10375	13500	14500	9438	14000
Range of far visual acuity (6 m)	20/17-20/40	20/13-20/20	20/20-20/35	20/22-20/35	20/13-20/40	20/20-20/35
Range of near visual acuity (1 m)	20/18-20/35	20/13-20/25	20/30-20/70	20/40-20/100	20/13-20/35	20/30-20/100
Lane typically driven on a 3-lane highway: L-Left; C-Center; R-Right	L 2, C 2	C 3, R 1	R 4	C 2, R 2	L 2, C 5, R 1	C 2, R 6
# of subjects with at least 1 accident in the last 5 years	2	2	1	0	4	1

<u>Test Materials and Equipment</u>

<u>Simulator</u>

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 3).



1. 1985 Chrysler Laser mockup with simulated hood
2. 8'X10' projection screen with 3M hi-white encapsulated reflective sheeting
3. PMI Motion Technologies ServoDisk DC motor (model 00-01602-002 type U16M4) with Copley Controls Corp. controller (model 413) and power supply (model 645)
4. 3-spoke steering wheel
5. Sharp color LCD projection system (model XG-E850U) for instrument panel
6. 28.5"X72" plexiglas screen
7. Sharp computer projection panel (model QA-1650)
8. 3M overhead projector (model 9550)
9. Audio rack
10. 2-button keypad
11. Power Macintosh 9500/200
12. Power Macintosh 7100/80AV
13. Power Macintosh 8500/120
14. Macintosh Quadra 840AV
15. Video rack
16. Panasonic low level light camera (model WV-BP510)
17. Panasonic "lipstick" cameras (one hanging from ceiling, model GP-KS152)
18. Power Macintosh 9500/150
19. Sony speaker system (model SR6-48)
20. Mitsubishi 15" flat panel LCD monitors (model LXA520W)
21. Modified night light to illuminate fingers

Figure 3. Plan view of UMTRI's Driver Interface Research Simulator

Simulated Roads

The simulated roads were designed to impose 3 levels of workload by varying road curvature (straight section, moderate curve, and sharp curve). The straight section was assumed to have the lowest visual workload level. The 2 curved sections 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). In the current study, only curves of 3 and 9 degrees of curvature were used. In the aforementioned study, the visual demand within curves was found to be greater at the beginning of curves and to decrease to a steady state after approximately 150 m. Therefore, the HUD presentation task of this study was limited to 200 m after the beginning of curves and the curves were designed to be long enough to maintain constant visual demand values (approximately 2 minutes). In the real world, it would be unlikely to encounter such long constant radius curves. Moreover, the sharpest curve, which spanned over 540 degrees, could only be built in a virtual environment. However, for the purpose of this experiment, the long curves provided steady workload.

All lanes of the two-lane road were 3.66 m (12 feet) wide, with alternating left and right curves. See Table 5 for additional information about the road geometry.

Table 5. Road Geometry. Components of 6 roads used in this study

	Data Collection Roads					Practice Roads		
Section	Duration [mm:ss]	Curve Radius [m] and Direction				Duration [mm:ss]	Curve Radius [m] and Direction	
		Road 1	Road 2	Road 3	Road 4		Road 5	Road 6
Start	0:25	0	0	0	0	0:25	0	0
1	2:00	582 R	582 L	0	0	0:30	0	0
Transition	0:20	0	0	0	0	0:20	0	0
2	2:00	194 L	194 R	194 R	194 L	0:30	582 R	194 L
Transition	0:20	0	0	0	0	0:20	0	0
3	2:00	0	0	582 L	582 R	0:30	194 L	582 R
Transition	0:20	0	0	0	0	0:20	0	0
4	2:00	194 R	194 L	194 L	194 R	0:30	582 L	194 R
Transition	0:20	0	0	0	0	-	-	-
5	2:00	0	0	0	0	-	-	-
Transition	0:20	0	0	0	0	0:20	0	0
6	2:00	582 L	582 R	582 R	582 L	0:30	194 R	582 L
End	0:20	0	0	0	0	0:20	0	0

HUD Configuration - Hardware setup

The simulated HUD consisted of an acrylic sheet on which the images from 2 flat-panel LCD monitors were visible as reflections. As Figure 4 shows, the subjects saw these reflections superimposed on the road scene. Figure 5 shows the physical layout of the simulated HUD.

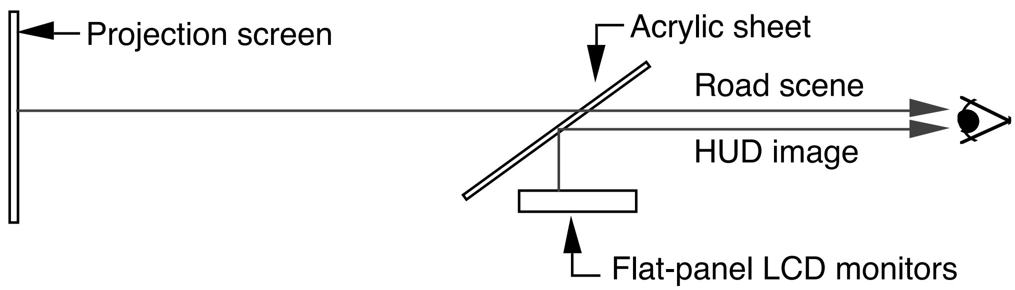


Figure 4. Simulated HUD

Figure 5. Setup of HUD unit in the simulator

HUD Configuration - locations on the HUD

Figure 6 shows the 8 locations of the messages that were presented. These 8 locations were the best of 15 (3 rows of 5 columns) examined in a prior HUD study (Yoo, Tsimhoni, Watanabe, Green, and Shah 1999). The omitted locations were 5 locations in the top row and the 2 bottom corners. The center location was at eye level and the other locations were spaced apart 5.5 degrees horizontally and 7.5 degrees vertically. (See Appendix E for a detailed schematic of the implementation on two LCD flat-panel displays)

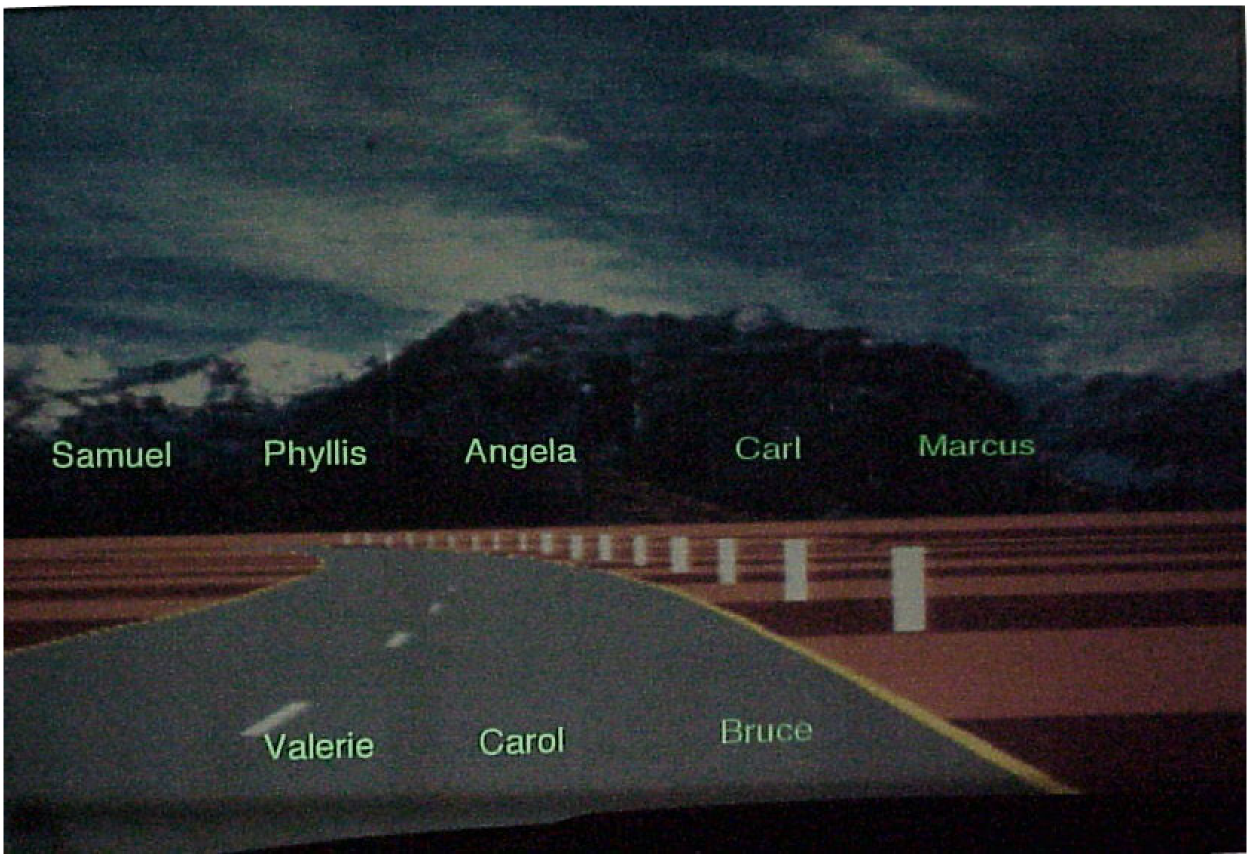


Figure 6. Image of HUD messages (only one name appeared at a time).

HUD image size and characteristics

The HUD messages appeared at a focal distance of 100 ± 5 cm from the subject's eyes. Capital letters spanned a vertical visual angle of 11 milliradians from the subject's eyes, as can be seen in Figure 7. (See Table 6 for a tabular summary of some important characteristics of letters in the current study as compared to the book of HUD (Weintraub and Ensing, 1992) and to military standards (MIL-D-81641, and MIL-M-18012B).

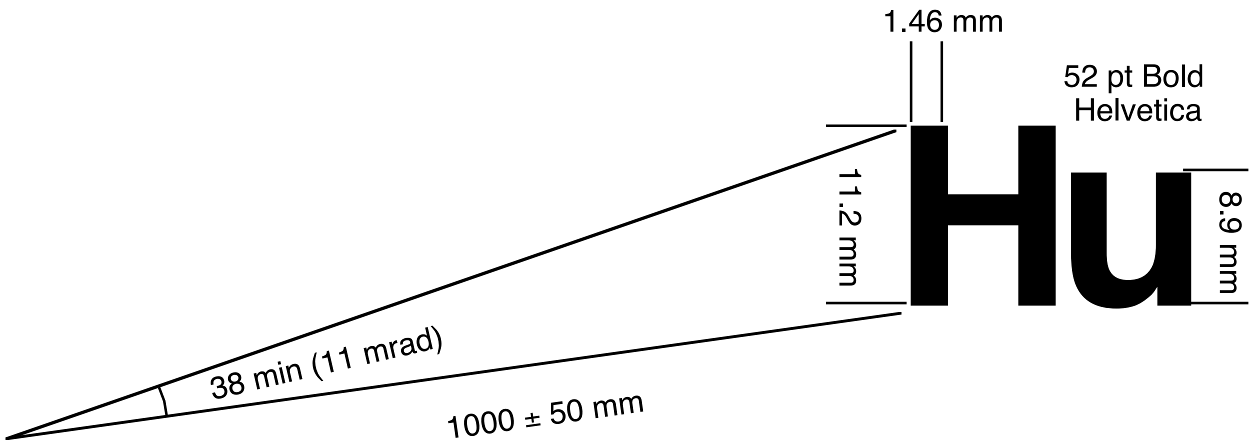


Figure 7. Visual angle and font size used for HUD messages in the current study

Table 6. Standards for HUD character size (Weintraub and Ensing, 1992)

Required	MIL-D-81641	MIL-M-18012B	The Book of HUD	Current study
Character Height	> 30 min	28 min - 41 min	> 28 min	Caps 38 min Lower 30.5 min
Stroke width	1.0±0.2 mrad			1.5 mrad
SW/H ratio		1:6 - 1:8	1:5 - 1:8	1:6.1 - 1:7.6

Name choice

The names that were presented on the HUD were taken from a list of 300 popular names based on the 1990 U.S. Census list and listed on the internet (www.babynamer.com) under the 'Popularity: Classic Star' subsection. One hundred and fifty two common American first names were selected based on the criteria in Table 7.

Table 7. Criteria for choosing names to present on the HUD

Criteria for presented names	Examples	
	Accepted	Rejected
Popular, well known to young and old US subjects	Adam, Brian, Susan, Wendy	
intermediate length (no less than 3 characters, no more than 7)	Shortest: Lori, Gail, Joel Longest: Michael, Eleanor	Too short: Eva, Don Too long: Jacqueline
Typically used for only one sex.	Male: Jeffery, Steven Female: Rachel, Helen	Both: Robin, Chris
No homophones		Steven-Stephen
Minimize repetition of one character for all names of the same gender		Some female names ending with 'a' were rejected

Finger switches - hardware

Subjects responded to the HUD messages by pressing one of two switches, the left index finger switch for male names, and the right index finger switch for female names (Figure 8). Connecting the switch to the finger rather than to the steering wheel allowed subjects to move their hands freely and the short switch travel minimized movement time.

Figure 8. Finger switches were attached to the subjects' index fingers

Software - SuperCard program

A custom SuperCard program (SuperCard ver. 3.6, IncWell Digital Media Group), running on a Power Macintosh 9500/150, was used to display the HUD messages.

A recent simulator software modification allowed for serial communication between the main simulator computer and the secondary task computer running the SuperCard program. The simulator used script files to determine where or when commands should be sent to the secondary computer for each run. The communication protocol with the secondary computer consisted of a command for the start and end of each HUD presentation interval and a code for the position to be used.

For the names to be seen properly by the subjects, the images were inverted (left to right) and rotated 90 degrees clockwise for the left LCD and 90 degrees counter clockwise for the right LCD. As soon as the name was presented, a timer began measuring the time until the subject responded by pressing one of the finger switches. If a finger switch was pressed within 6 seconds of HUD presentation, the time and the switch pressed were recorded (to the nearest 33 ms). Immediately after the switch was pressed, the program removed the name from the HUD to prevent interference.

Test Activities and Sequence

The subjects began by completing a biography form (Appendix A), and a consent form (Appendix B) followed by performing a vision test and then sitting in the driving simulator (Table 8– activity P1). Their seating height was calibrated so that the middle HUD position was at their line of sight with a temporary lead vehicle. Their focal distance from the center HUD was calibrated to 100 cm (39 inches) by adjusting the seat. Next, all the names that would later appear on the HUD were presented on two cards (one card for each gender) so that subjects could verify they were familiar with all of the names.

Table 8. Summary of activities and their sequence

Trial	Activity	Practice	Test	Stationary	Driving	Road Number (see note) A	B	Trials	Time (min)
P1	Pre-experiment forms and setup	-	-	-	-	-	-	-	8
01	Detection	✓		✓				8	4
02			✓	✓				16	5
03	Driving	✓			✓	5	6	-	5
04			✓		✓	6	5	-	5
05	Detection and driving	✓			✓	5	6	8	5
06			✓		✓	1	2	48	15
07	Gender-Naming	✓		✓				16	5
08			✓	✓				16	5
09	Gender-Naming and driving	✓			✓	6	5	8	5
10			✓		✓	1	2	48	15
P2	Break	-	-	-	-	-	-	-	5
11	Gender-Naming and driving 2		✓		✓	3	4	48	15
12	Gender-Naming 2		✓	✓				16	5
13	Detection 2		✓	✓				16	5
P3	Post-experiment forms	-	-	-	-	-		-	8
						Total		248	115

Note: The road numbers in this table refer to the road numbers in Table 5.

The testing started with practicing the detection task. Subjects had to click on a switch, located on their right index finger, as soon as they detected the appearance of a word in each of the 8 locations on the HUD (activity 01). After the practice, the procedure was repeated and data were collected twice for each location (total of 16 trials). Location was randomized within each block of 8 locations (activity 02). Next, The subjects practiced driving the simulator with nothing appearing on the HUD. The vehicle was driven with automatic cruise control engaged at 72.5 km/h (45 Mi/h). Subjects were instructed to drive in the right lane of the two-lane road (activity 03). After the practice, a similar road was driven again and driving data were collected (activity 04). The two tasks, driving the vehicle and detecting words on the HUD, were then practiced together (activity 05) and repeated for data collection. In the detection and driving session each HUD location was used 6 times for a total of 48 trials (activity 06)

A similar protocol was performed for the gender-naming task. First, subjects practiced responding with their right or left index finger to names presented on the HUD for a total of 16 trials (activity 07). (To reduce confusion, the finger that was used corresponded to the side at which names were presented to the subjects at the beginning of the experiment. After the practice, the same procedure was repeated for data collection (activity 08). Then, subjects practiced the task while driving (activity 09). Finally, they performed the gender-naming task while driving for 48 trials (activity 10). After a short break, the task was repeated on a slightly different road (activity 11). Finally, the gender-naming task was repeated for 16 trials without driving (activity 12) and then the detection task was repeated for 16 trials (13). After completing these activities, subjects filled out a post-test evaluation form (Appendix D). Finally, they were thanked for their participation and were paid $35. (The experimenter's data collection sheet appears in Appendix C)

<u>Data analysis</u>

Data transformation and analysis was done using spreadsheets (Excel 98 for Macintosh, Microsoft Corp., Seattle, WA) and Macro mini programs (Visual Basic 98 for Macintosh, Microsoft Corp., Seattle, WA). The data were analyzed by analysis of variance (ANOVA) using a statistics software package (Statview 5.0.1 for Macintosh; SAS Institute Inc., Cary, NC). All reported p-values are for 2 tailed tests.

RESULTS

Overview

Each of 4 groups of dependent variables: (1) response times to HUD messages, (2) driving performance, (3) errors, and (4) subjective were examined separately. In the ANOVA reported, the main factors were HUD location (8 levels), driving workload (3 levels), type of task (detection, reading), task combination (alone, while driving), age (young, old), sex, and participant nested within age and sex.

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Response Time Analysis

Data Transformation

The response time data were transformed by applying a natural logarithm to provide a better fit to a normal distribution (a requirement of ANOVA). The values presented in the report have been transformed back (they are the exponents of the log transformed values). (See Yoo, et al, 1999, for a more detailed discussion of the transformation)

Justification for dropping subject 5:

A total of 6.2% of subject 5's responses were incorrect. In a retrospective examination of the videotapes, the experimenters noted that the subject looked extremely sleepy. Therefore, the data for this subject were dropped.

Workload Level

The subjects completed the detection tasks and reading tasks during four simulated levels of workload: not driving, driving on a straight road, driving on a moderately curved road, and driving on a sharply curved road. The mean response times for each level are represented in Figure 9. The main effect of curvature (workload) was significant ($p=0.0002$) with the mean response time increasing with workload, though the differences between not driving and driving on a straight road were quite small. In terms of the effect of the secondary task, the mean response times were about 620 ms longer for the reading task than the detection task for all workload levels ($p<0.0001$). There was no task workload interaction.

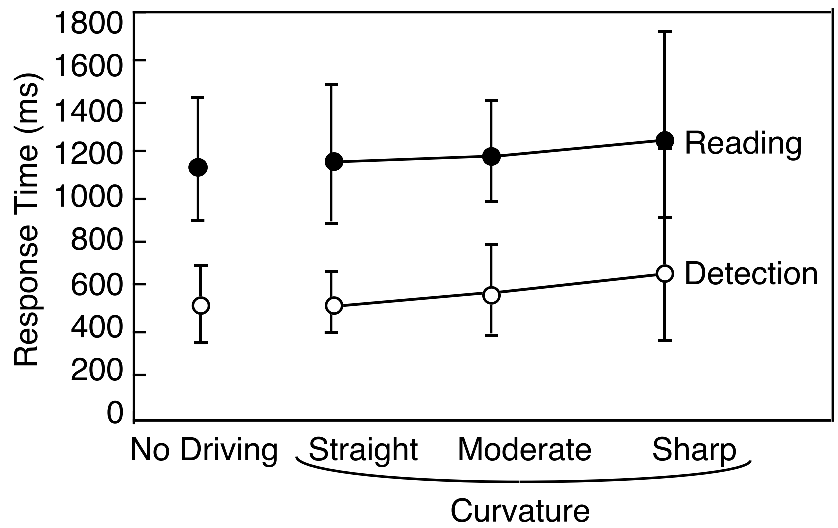


Figure 9. The effect of driving workload on response time for both reading and detection tasks

HUD Position

Differences in the mean response times by location were small and not statistically significant for the detection task (p=0.21). However, there were slight but statistically significant differences (due to eccentricity) for the reading task (p=0.0002), which might be attributed to an eccentricity effect (Figure 10). Subjects responded more quickly to HUD messages presented in the center locations (3 and 7) than those in the outer locations. However, the interaction between HUD position and secondary task was not significant (p=0.085). This absence of sizeable differences due to location was expected, as prior work (Yoo, Tsimhoni, Watanabe, Green, and Shah) had shown difference between locations to be small for detection. Figure 10 presents a comparison of mean detection time between the two studies.

The baseline data sets of both studies fall within a 5 percent difference (515 ms in the previous work versus 491 ms in the current). This suggests that the difference in signal properties (amber triangle in the previous work versus green word in the current) and the difference in the physical properties of the response key (keypad button versus finger-mounted switch) did not affect the overall response times, or possibly canceled each other. The data from the main experiment, however, have extremely different values (925 ms versus 562 ms). The detection of the warning signals while performing the video monitoring task ("driving") in the previous experiment was 363 ms slower than the detection of scrambled names while driving the simulator in the current experiment. The time difference can be explained by the nature of the detection tasks in each of the studies. In the previous study, the subject performed a two-choice reaction task, in which the detection response was mapped to one key (the HUD key) but 3 additional events were mapped to a second key (the road event key). In contrast, in the current study, the detection task always involved only one key (simple reaction task) thus eliminating the need to select one of two responses. Since the current experiment had not been designed to test the reasons for this difference, this explanation is provided as an unproven hypothesis.

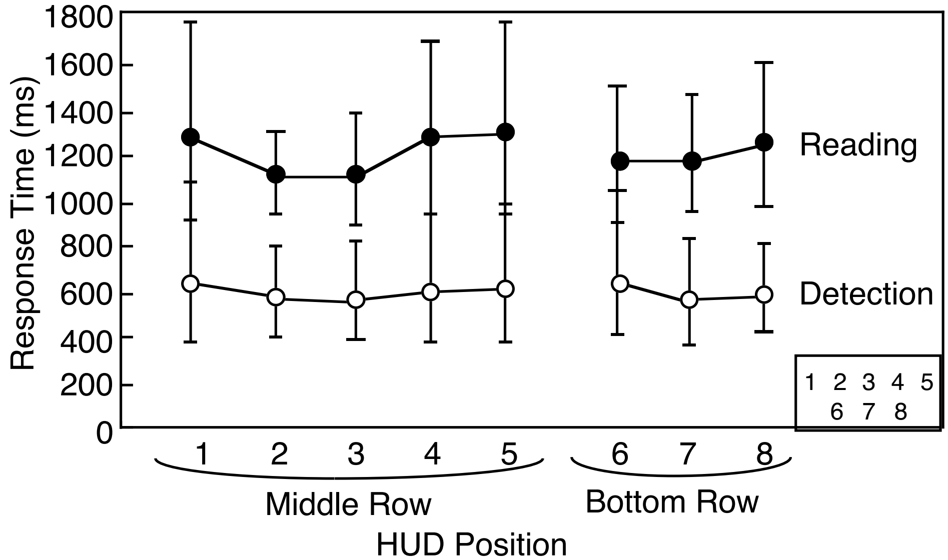


Figure 10. The effect of HUD position on response times for both reading and detection tasks

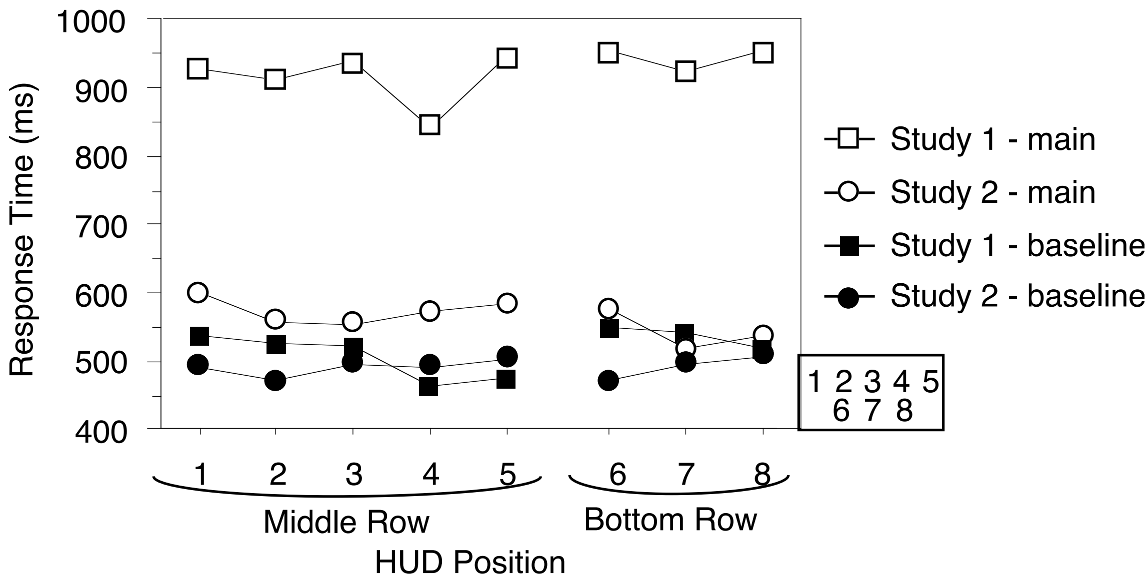


Figure 11. Comparison of detection time in previous work (Study 1) (Yoo, Tsimhoni, Watanabe, Green, and Shah, 1999) and in the current study (Study 2)

HUD Position and Curve Direction

There was a significant interaction between HUD position and curve direction (p=0.001) for the reading task, as can be seen in Figure 12. Detection times followed a similar trend (p=0.008). When driving in curves, locations close to the line of sight (to the right for right curves, to the left for left curves) were more rapidly detected and processed than those on the opposite side of the curve.

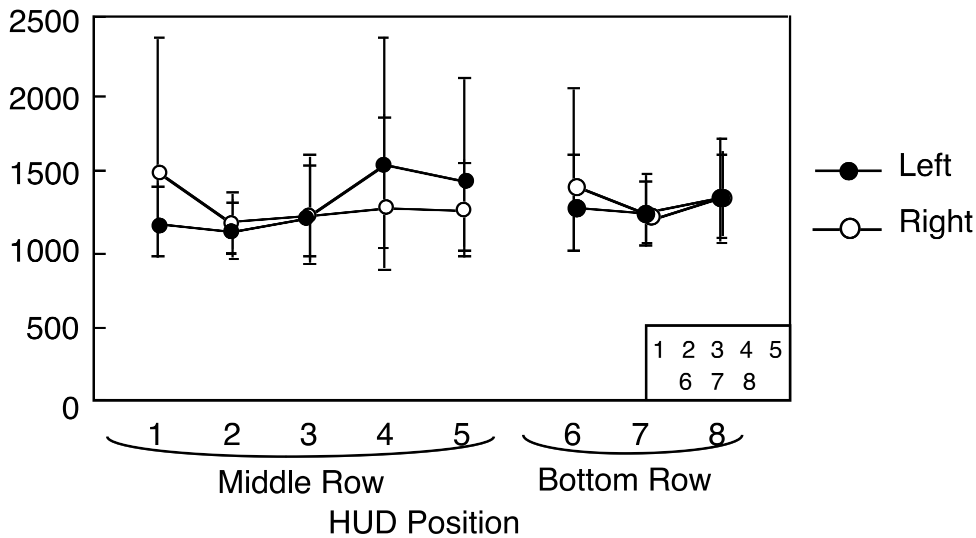
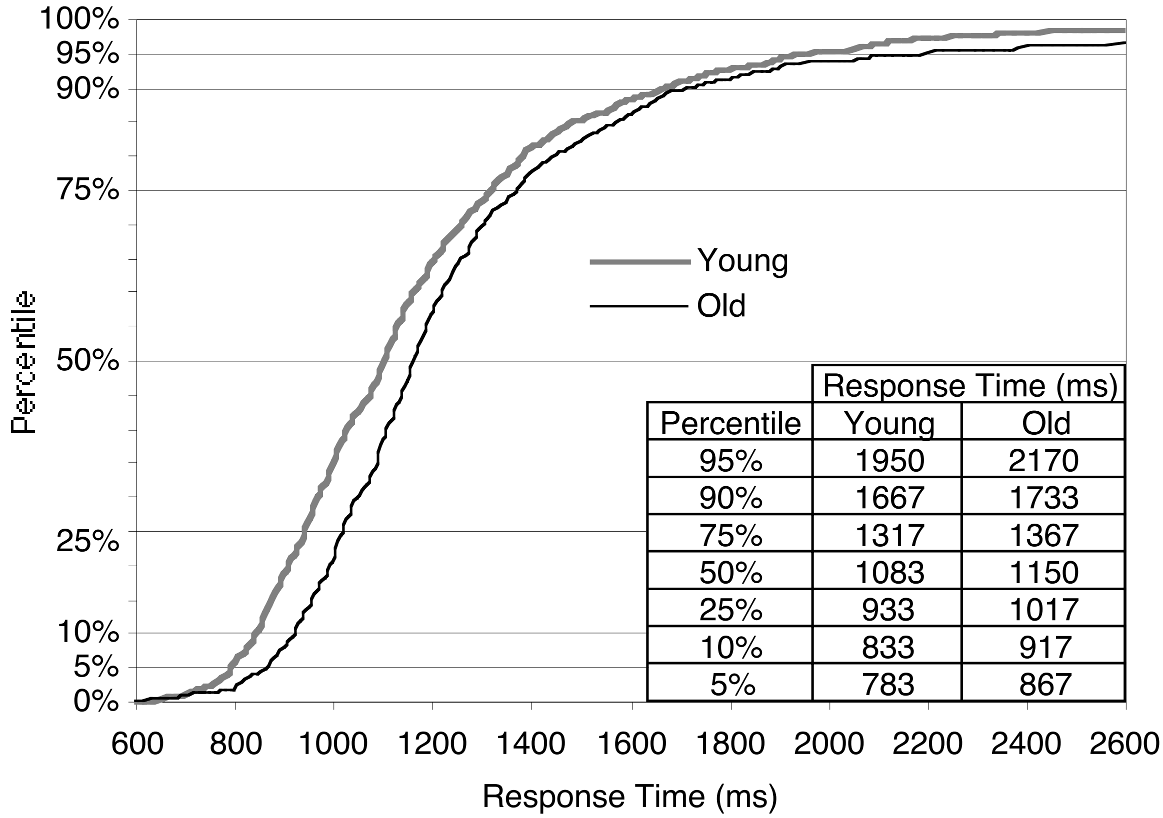


Figure 12. The effect of HUD position and curve direction on reading task response times

Age and Gender Effects on Response Time

Neither age nor gender significantly affected response time during the reading task. The mean response time for younger subjects (1167 ms) was only slightly faster than the mean response time for older subjects (1233 ms). There was no difference between men and women, as their mean response times were approximately the same (1200 ms). Figure 13 shows the cumulative distribution of response times in the reading task for both young and old subjects. There was a consistent shift of approximately 100 ms in the cumulative distributions due to age.



	Response Time (ms)	
Percentile	Young	Old
95%	1950	2170
90%	1667	1733
75%	1317	1367
50%	1083	1150
25%	933	1017
10%	833	917
5%	783	867

Figure 13. Response time percentiles for the reading task

Fatigue and Learning Effect

The mean response time of the subjects increased by approximately 150 ms from the detection pre-test to post-test, possibly due to fatigue or boredom. The reading portion of the experiment resulted in a similar increase of roughly 100 ms from pre to post-test for the older subjects. On the other hand, the response times of the young subjects decreased by roughly 100 ms, possibly due to learning.

Driving Performance Analysis

The standard deviations of lateral lane position and steering wheel angle were obtained for all driving runs for the 5 second interval immediately after the presentation of a HUD message.

Secondary Task Type

As shown in Figure 14, the standard deviation of both lane position and steering wheel angle were consistently less for the older subjects. The difference was statistically significant for lane position (p=0.001) but not for steering wheel angle (p=0.17). In general, increasing the task complexity decreased performance (the standard deviations increased), except for the standard deviation of steering wheel angle for older subjects, were there were no differences.

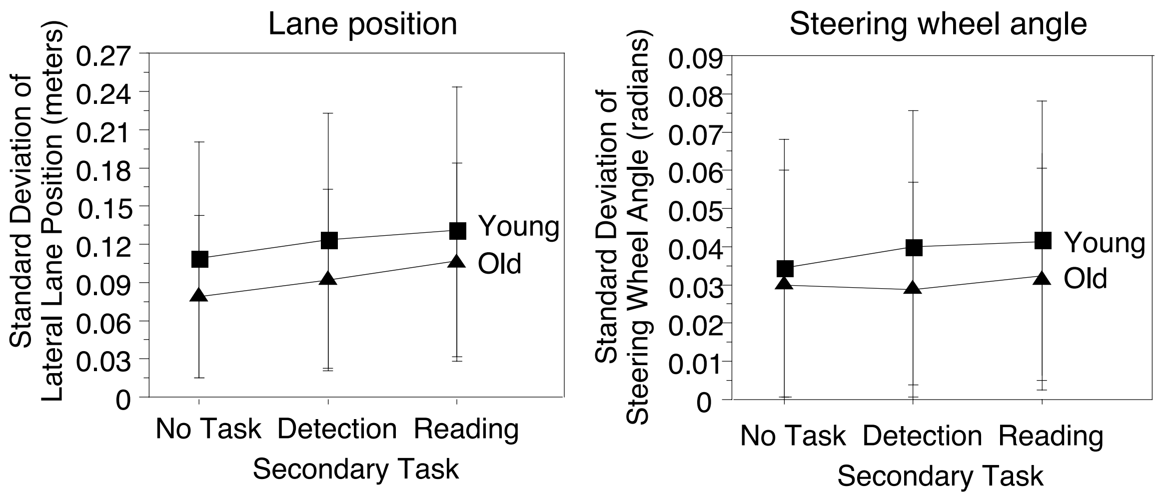


Figure 14. The effects of secondary task and age on driving performance

<u>Workload Level</u>

Driving was more variable when the HUD was presented on straight sections (low workload) than sharp sections (highest workload) (Figure 15). Performance also degraded when the radius of curvature decreased. Once again, the younger subjects did not perform as well as the older subjects. A significant interaction between workload level (road curvature) and age existed for both performance measures; the significance level for lateral lane position (p=0.001) and steering wheel angle (p=0.004) were quite similar.

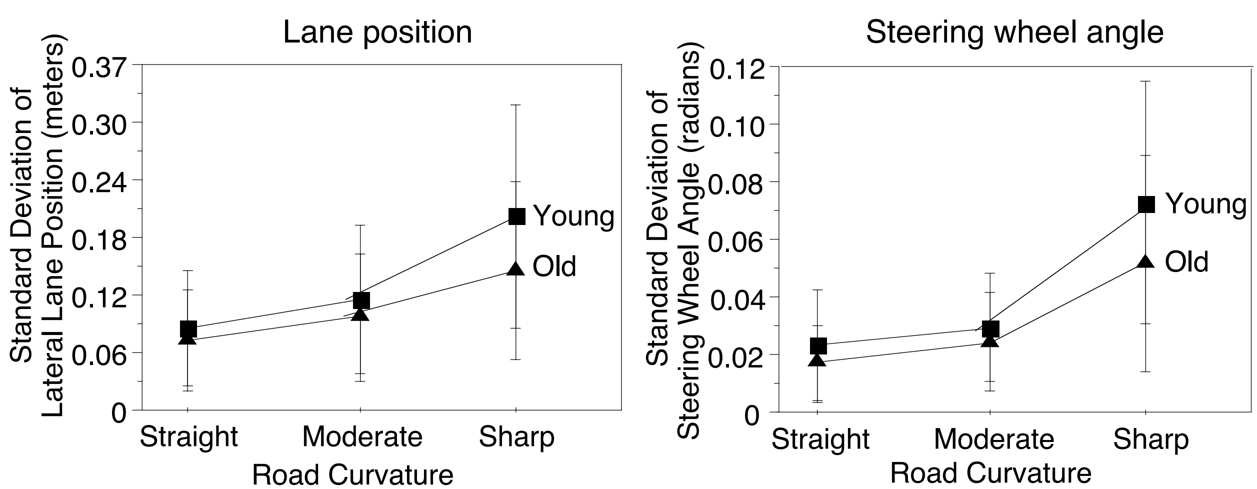


Figure 15. The effect of road curvature on driving performance

<u>HUD Position</u>

The location of the displayed message on the windshield had an effect on driving performance in terms of standard deviation of lateral lane position as there were statistically significant differences (p=0.005). However, standard deviation of steering wheel angle was not affected (p=0.15) (Figure 16). Performance for HUD position 3 produced slightly larger means and variances for both performance measures. The presentation of the HUD in the center of the windshield at eye level may have interfered with the road and any event directly in front of the vehicle, resulting in this minor performance difference.

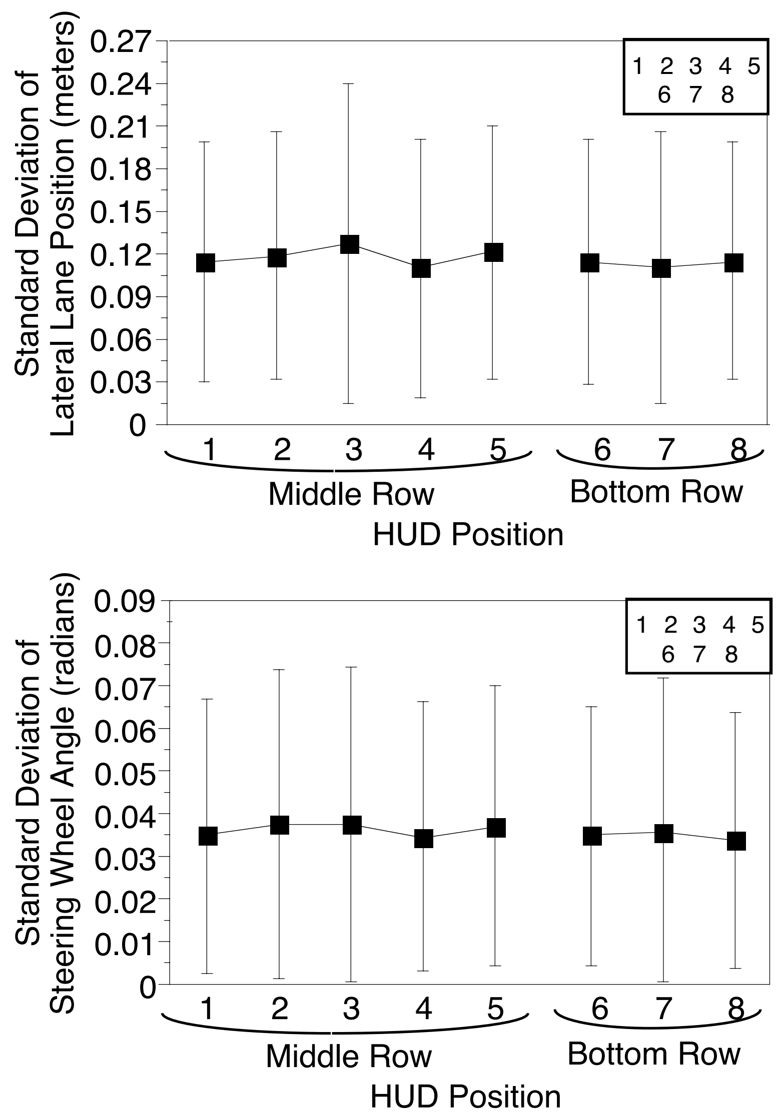


Figure 16. The effect of HUD Location on driving performance

Age and Gender

Age was statistically significant for standard deviation of lateral lane position (p=0.05), but not steering wheel angle (p=0.10) (Figure 17). Gender was not statistically significant for either driving performance measure. For both measures, older males performed better than younger males.

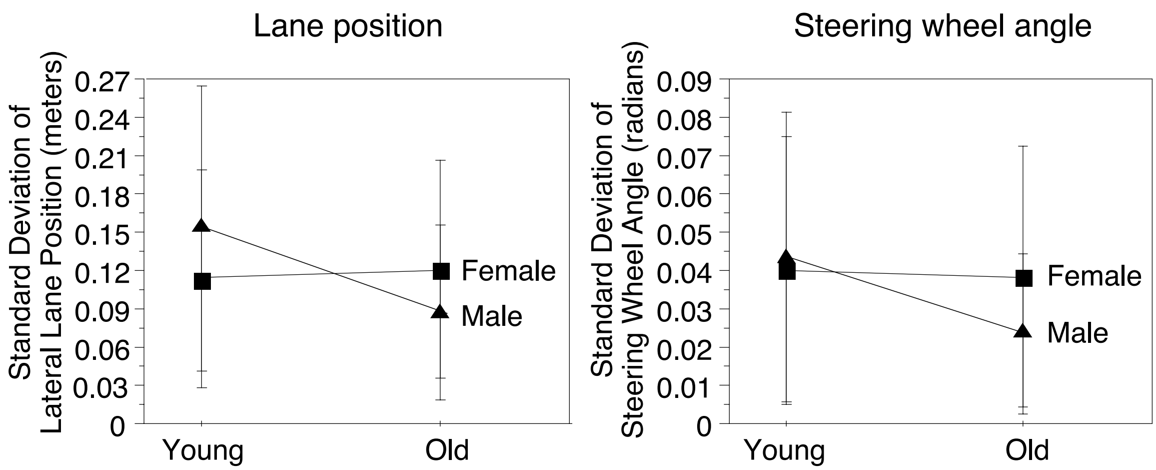


Figure 17. The effect of gender and age on driving performance

Error Analysis and Tradeoffs

Response Accuracy vs. Driving Performance and Response Time

The percent missed responses of each subject increased as a function of performance measure. This trend suggests that the subjects who had poor mean response time and driving performance also missed more messages.

In contrast, the percent incorrect responses of each subject decreased as a function of performance measure (Figure 18). There was a slight tradeoff between accuracy and both mean response time and driving performance: subjects who drove well and responded quickly had a higher percentage of incorrect responses. It was also observed that incorrect responses were slightly faster than correct responses.

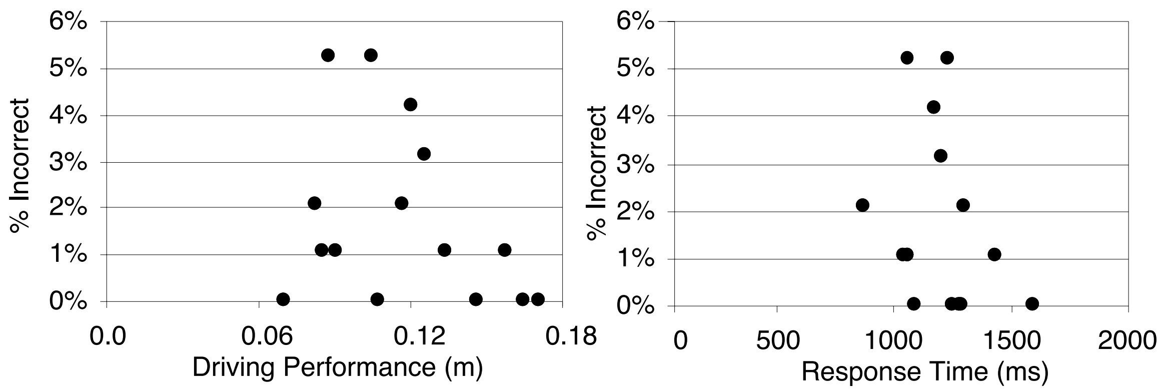


Figure 18. Percent incorrect responses

Response Time vs. Driving Performance

A slight upward trend was found for mean response time as a function of mean driving performance (Figure 19). Generally, subjects with better driving performance responded to HUD messages quickly, while subjects with worse driving performance responded slowly. A linear regression verified the positive trend, although the R-squared value was very low (R-squared = 0.14). It was noted that most of the subjects' mean response times fell within a small range (300 ms) while the driving performance measure (standard deviation of lateral position) fell between 0.06 m and 0.18 m.

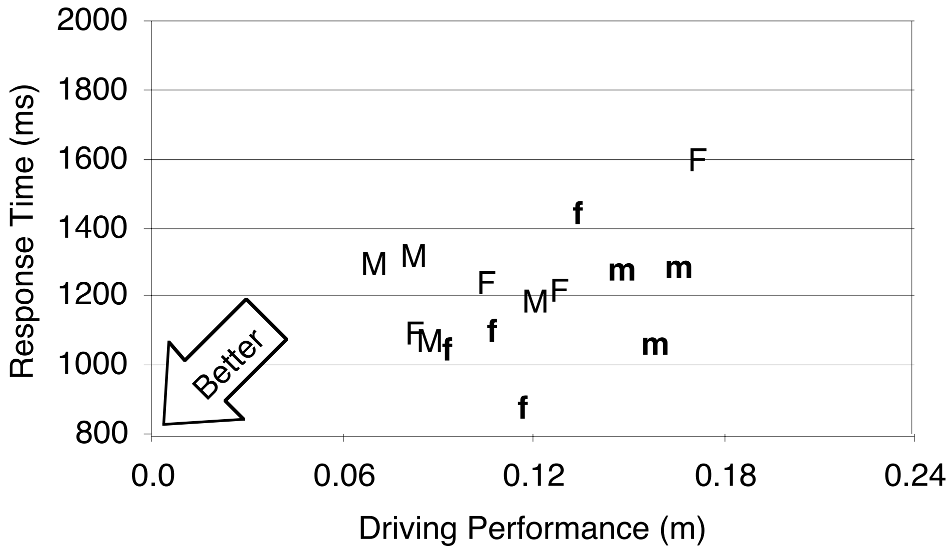


Figure 19. Tradeoff between response time and driving performance (the standard deviation of lateral position)

Given the weak relationship between errors and driving performance (Figure 18) and response time and driving performance (Figure 19), the two non-driving measures were combined to clarify the relationship. Specifically, the mean response time data were adjusted to penalize subjects for errors (Figure 20).

Three trend lines were evident for the percent incorrect vs. driving performance, while two were clear for percent incorrect vs. response time (Figure 18). Regression lines were fit to the appropriate data points (all R-squared values > 0.82), and the slopes were averaged in order to find the adjustment ratio for each performance measure. The ratio was split so that each performance measure accounted for half of the errors. Thus, for every 1 percent incorrect, the mean response time was increased by 65 ms, and the mean driving performance was increased by 0.007 m. The resultant data represent the hypothetical performances of all the subjects, where the percent incorrect was linearly adjusted to 0%. A linear regression fit proved a similar positive trend, although the R-squared value was slightly lower (R-squared = 0.10) than the actual data set.

In the adjusted figure, the difference between older and younger subjects became more apparent. Three older men and 2 older women shifted to a below-average overall performance, mainly because they made more errors than others.

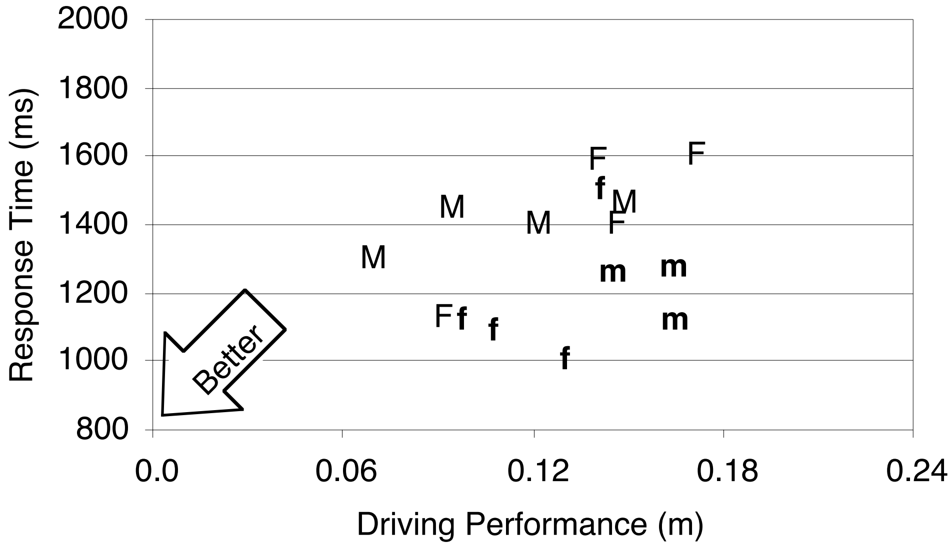


Figure 20. Adjusted mean response time as a function of mean driving performance.

<u>Response Accuracy vs. Workload Level</u>

Relative to workload level, the percent incorrect responses were all quite similar (Figure 21); the means were within .62% of each other. Thus, increased workload did not cause the subjects to make more errors.

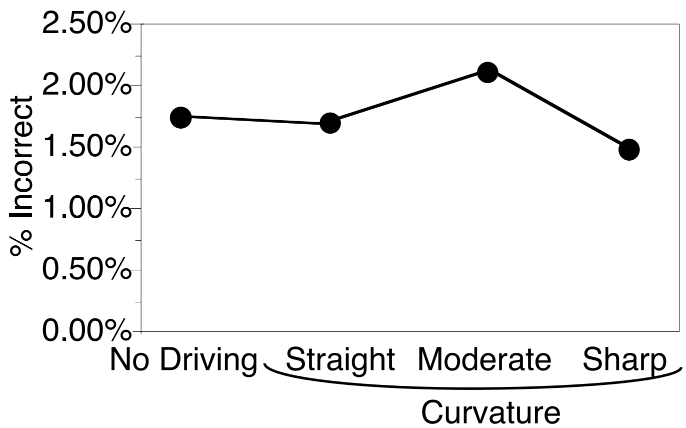


Figure 21. Percent incorrect responses as a function of workload

On the other hand, the percent missed responses as a function of workload level for both reading and detection tasks produced a logarithmic trend (Figure 22). Missed responses were minimal for no driving, straight road, and moderate curve. However, the sharp curve caused 3.3% of the HUD messages to be missed during the detection task, and 2.1% were missed during the reading task. This distinct increase may be related to the curve direction and HUD position effect mentioned earlier (see Figure 12).

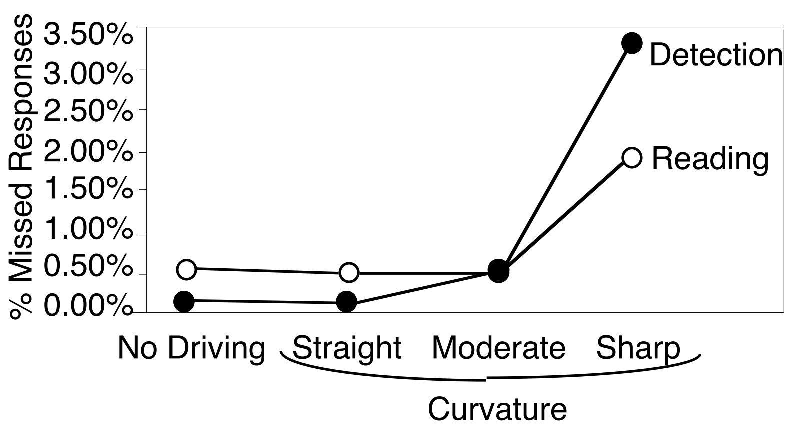


Figure 22. Percent missed responses as a function of workload

Subjective Evaluation

Preference for Location

Figure 23 shows the mean ranks (1=best, 8=worst) for each message location obtained from the post test evaluation. The best location was slightly right of center in the middle row with a mean rank of 3.0. The worst location was leftmost in the middle row with a mean rank of 6.2. An eccentricity effect was apparent; the subjects thought the center locations were much better than the outer locations.

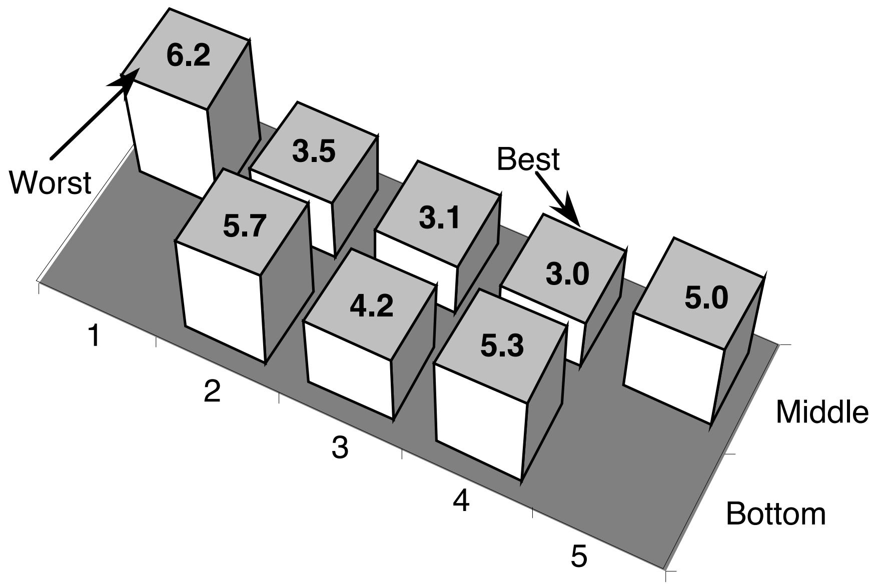


Figure 23. Subject responses for 'best' and 'worst' locations for a HUD

Figure 24 shows subject location preference for displaying caller ID and pager message indicators. The 2 preferred locations (each desired by 4 of the 16 subjects) were to the right of the center in the middle row. These results were consistent with the overall preferences described earlier. However, while half of the older subjects preferred the rightmost location, young subjects were split between the right and the left. Older subjects appeared more concerned that the HUD message would not interfere with their normal driving responsibilities ("not necessary for driving – therefore should not interfere").

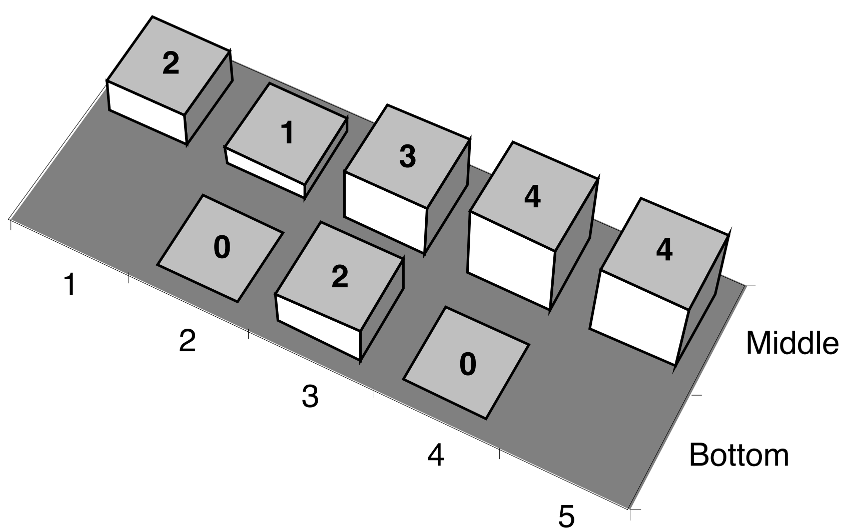


Figure 24. Subject responses for the 'preferred' location for caller ID or pager message indicator

Subjective Evaluation of Task Difficulty

Figure 25 shows the mean rating (0=extremely easy, 10=extremely hard) of the difficulty of each task combination. Subjects felt that the difficulty increased as curves became sharper (radius of curvature decreased) variance increased as well, which distinguished a larger range of subjective difficulty in the curved sections of road. Also, the younger subjects ranked the task on the sharply curved section 2.3 higher than the older subjects (0.9 higher for the moderately curved section), although the age effect was not significant (p=0.19). However, age and workload level (or curvature) significantly interacted (p=0.07).

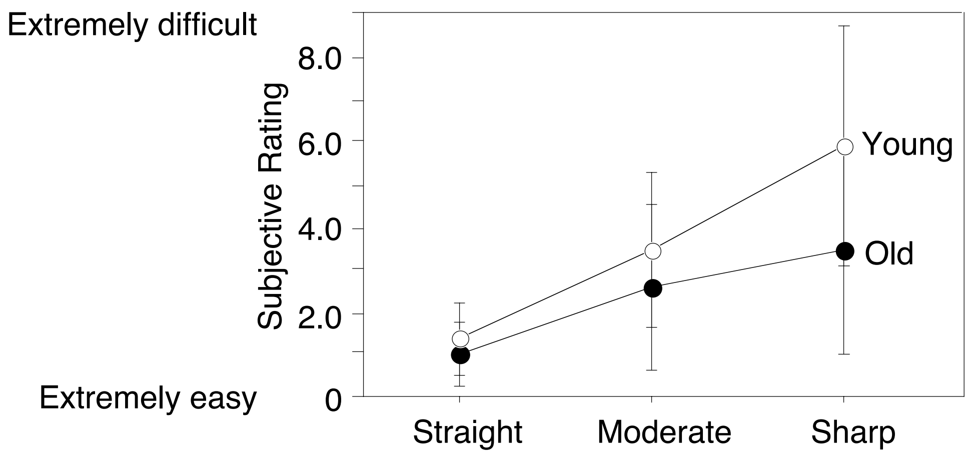


Figure 25. Difficulty ranking for each workload level split by age

Subjective Evaluation of Simulation Fidelity

Subjects indicated the realism of the simulator (0=very artificial , 10=very real) with regard to 4 attributes: steering, graphics (road scene), sound (engine and road sounds), and vibration. The mean ratings for steering, sound, and vibration were all approximately 5.4; thus all were moderately real. The mean rating for graphics was 3.6, suggesting a fairly artificial road scene.

Subjective Description of the Response Process

All subjects reported that they looked at the road while driving, rather than searching the HUD for a new message. Twelve subjects reported glancing at the HUD message immediately after it appeared, while only 3 reported checking the vehicle direction before responding. One subject noted that the swiftness of his response “depended on the location of the message” and the direction of the curve. All subjects except one reported looking at the HUD only once to get the answer. Finally, 11 subjects reported that they returned their view to the road when deciding which finger switch to click. Two subjects reported that they continued to gaze at the HUD, and the remaining 2 reported a combination of the two.

CONCLUSIONS

1. What is the effect of HUD message position on response time (and errors) to messages, on concurrent driver performance, and on driver subjective preference?

The time to read a name on a HUD was significantly affected by where it was presented, even when the alternatives were all reasonably good, as determined by a prior experiment. Response time increased with the eccentricity of the locations from straight-ahead. The effect of HUD position on response time to the reading task was significant. The center positions had mean response times of 1100 ms, whereas the outer positions had mean response times of 1250 ms. In contrast, detection time (typically 600 ms) was not significantly affected by where the message appeared. Further, when driving in curves, locations close the line of sight (to the right on right curves, to the left on left curves) were detected and processed significantly more rapidly than those on the opposite side of the curve. Since most of the difference due to eccentricity was found in the reading task but not in the detection task (p=0.08), one might conclude that the need to fixate and to make a decision were the main source of delay.

The effect of HUD position on driving performance was significant only because when the HUD was presented at the center position, the standard deviation of lateral position was larger. In all other positions, driving performance did not differ as a function of HUD position.

Subjects thought that the three center positions in the middle row were better than the other positions. The most preferred position was 5 degrees to the right of the center, at eye level. When asked where they would have preferred a HUD in their own vehicle, most subjects preferred the right side of the middle row, even though some had acknowledged that their response would not be as fast.

2. What is the effect of driving workload on response time to messages and on concurrent driving performance as a function of message location?

Increasing driving workload significantly increased detection time and response time in the name reading task. Response time on sharper curves (675 ms) was slower than on straight sections (545 ms). The effect of workload was similar in magnitude for the detection task (1265 ms on sharp curves and 1175 ms on straight sections). Thus, while detection was affected by workload, the additional stages required by the reading task were not affected by workload.

In agreement with the slower response times, more HUD messages were missed while driving on sharper curves. However, the number of errors (not pressing the correct switch) was not affected by driving workload at all.

Driving was more variable in sharp curves than in moderate curves or straight sections (standard deviation of lateral position 0.17 m and 0.08, respectively). Interestingly, the effect of road curvature was larger for young subjects than for old subjects. The driving variability of young subjects on curves was significantly larger than that of old subjects.

Subjects reported that performing the HUD task was more difficult in sharper curves. As in the driving performance, young subjects seemed more affected by the effect of curvature.

3 & 4. How do driver age and gender affect performance? How do subjects tradeoff performance in the driving (primary) and response time (secondary) tasks?

Although subjects received identical instructions, their performance levels in both tasks (driving and responding to HUD messages) were different. The driving performance of older men was less variable (lower standard deviations) than other age-gender groups. Older subjects performed the HUD task more slowly and with more errors than did younger subjects. A tradeoff analysis revealed that old subjects typically performed worse on the HUD task while performing better on the driving task. In contrast, young subjects performed worse on the driving task while performing better on the HUD task.

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APPENDIX A – BIOGRAPHY FORM

#: _____ Date: _______________

Pre Test Biographical Form

Name: ___________________________ **Date of Birth:** _____ / ____ / ____
month day year

(please circle:)

Male Female

email: _________
phone: _________

Left Handed Right Handed

Occupation: ____________________________
(if student: major. if retired: former occupation)

In how many times did you drive the UMTRI simulator before? ___________

What kind of motor vehicle do you drive the most?

make: ___________________ model: ____________ year: ____________

Miles you drive per year: _______________

How many years of driving? ______________ **Professional Driving?** ___________

Is the total miles driven in your lifetime over 30,000? yes no

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

If you were driving on a 3-lane highway, what lane would you typically drive in?

Left Center Right

Do you wear glasses (or contact-lenses) while driving?
(Glasses, Contact lenses, Reading glasses, Bifocal, Multifocal)

Do you wear glasses (or contact-lenses) in any other situation?
(Glasses, Contact lenses, Reading glasses, Bifocal, Multifocal)

Comments: ____________________________

FOR THE EXPERIMENTER ONLY

Far Vision: (Landolt Rings)

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

Field of View

L	85	70	55
R	85	70	55

Depth Vision

1	2	3	4	5	6	7	8	9
B	L	B	T	T	L	R	L	R

Color Vision

12 5 26 6 16

Near Vision

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

APPENDIX B – CONSENT FORM

SUBJECT CONSENT FORM
for Head-Up Display (HUD) Study

The purpose of this experiment is to examine driver behavior while using a head-up display. A HUD presents information on the windshield so that the information appears superimposed on the scene ahead. Commonly used in aircraft to show essential information such as airspeed and altitude, these displays allow operators to focus their attention on the scene ahead, a potential safety benefit. There is a considerable interest in using HUDs to present navigation guidance and other information to drivers. For example, if you receive a call on your car phone, the caller's name might be displayed on the HUD to let you decide if you want to answer now or forward the call to your voice mail.

In the experiment today, different words and names will appear on a HUD, to which you will respond by pressing a finger switch. You will perform this task while driving the simulator at a cruise-controlled speed of 45 miles per hour, and also when the vehicle is still. You will be videotaped throughout the duration of the experiment for analysis purposes.

The entire study will take approximately 2 and a half hours to complete. You will be paid $35 upon completion of the experiment.

Some people experience motion discomfort in the simulator. If this occurs, 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 763-379

APPENDIX C – DATA COLLECTION SHEET

Subject Number:____ Subject Initials:____ Group: A / B Circle: Y O / M F Date: / /

Experimenter's Data Collection Sheet(front)

VCR VCR

S :

W01 — Practice detection

B	7
B	1
B	8
B	4
B	6
B	2
B	5
B	3

S :

W02 — Task only detection

C	7
C	8
C	4
C	1
C	6
C	5
C	3
C	2
D	5
D	8
D	6
D	4
D	2
D	3
D	7
D	1

S :

W03 Practice

S :

W04 Driving

S :

W05 — Practice detect. wDr

E	5
E	7
E	2
E	8
E	4
E	3
E	6
E	1

S :

W06 — Task detection with driving

F	3
F	8
F	6
F	4
F	1
F	5
F	2
F	7
G	4
G	3
G	1
G	6
G	5
G	8
G	7
G	2
H	5
H	4
H	3
H	8
H	2
H	1
H	7
H	6
I	7
I	8
I	3
I	5
I	4
I	1
I	2
I	6
J	6
J	3
J	8
J	5
J	2
J	4
J	7
J	1
K	8
K	5
K	6
K	7
K	1
K	2
K	4
K	3

S :

W07 — Practice for only reading

		Name
L	7	Janet
L	2	Barry
L	1	Earl
L	8	Peggy
L	6	Doris
L	5	Rodney
L	3	Joyce
L	4	Frank
M	8	Roger
M	4	Cindy
M	1	Mike
M	2	Victor
M	3	Henry
M	6	Ellen
M	7	Crystal
M	5	Lori

S :

W08 — Task only Reading

		Name
N	2	Sharon
N	3	Ruby
N	5	Joseph
N	6	Anita
N	7	Aaron
N	8	Ralph
N	4	Curtis
N	1	Heather
O	8	Travis
O	1	Ruth
O	5	Ethel
O	6	Steve
O	7	Jeffery
O	3	Shirley
O	4	Richard
O	2	Irene

S :

W09 — Practice read. wDr.

		Name
P	5	Herbert
P	2	Ronald
P	3	Kelly
P	7	Jacob
P	4	Vincent
P	1	Sherry
P	6	Lisa
P	8	Brenda

L=male
R=female

S :

W10 — Task reading with driving

		Name
Q	7	Nathan
Q	6	Philip
Q	5	Leslie
Q	2	Steven
Q	1	Mary
Q	8	Adam
Q	3	Emily
Q	4	Sarah
R	8	Betty
R	4	David
R	2	Monica
R	3	George
R	1	Ricky
R	7	Alan
R	6	Tiffany
R	5	Susan
S	7	Megan
S	5	Tammy
S	3	Cheryl
S	1	Amy
S	6	Ernest
S	4	Edward
S	2	Alfred
S	8	Wayne
T	4	Sandra
T	1	Rose
T	2	Mark
T	8	Gail
T	3	Brian
T	5	Stanley
T	6	Johnny
T	7	Edith
U	1	Elaine
U	6	Wanda
U	7	Larry
U	2	Marvin
U	8	Norman
U	5	Leroy
U	4	Pamela
U	3	Eleanor
V	2	Keith
V	8	Janice
V	1	Teresa
V	7	Martin
V	5	Kevin
V	4	Nicole
V	3	Marie
V	6	Jason

S :

W11 — Task reading with driving

		Name
W	1	Beverly
W	7	Lillian
W	8	Gary
W	3	Alice
W	2	Paul
W	5	Joshua
W	6	Sean
W	4	Gloria
X	1	Nancy
X	4	Grace
X	6	Karen
X	8	James
X	7	Robert
X	2	Arthur
X	5	Jimmy
X	3	Judy
Y	6	Amber
Y	2	Michael
Y	5	Justin
Y	4	Laura
Y	7	Harold
Y	3	Craig
Y	1	Wendy
Y	8	Joanne
Z	6	Eugene
Z	4	Rachel
Z	2	Ryan
Z	5	Donna
Z	3	Lucille
Z	1	Willie
Z	8	Carrie
Z	7	Scott
$	2	Helen
$	6	Kyle
$	8	Russell
$	1	Charles
$	5	Gladys
$	4	Edwin
$	3	Annie
$	7	Evelyn
%	2	Peter
%	7	Walter
%	5	Diane
%	1	Albert
%	8	April
%	4	Esther
%	3	Debbie
%	6	Harry

S :

W13 — Task only reading

		Name
(	2	Patrick
(	8	Kathy
(	4	Bonnie
(	5	Rose
(	1	Judith
(	7	Joel
(	6	Melvin
(	3	Randy
)	7	Carol
)	8	Bruce
)	3	Angela
)	2	Phyllis
)	1	Samuel
)	4	Carl
)	5	Marcus
)	6	Valerie

S :

W14 — Task only detection

&	3
&	4
&	5
&	1
&	7
&	8
&	2
&	6
*	1
*	3
*	8
*	6
*	2
*	4
*	7
*	5

Start time
:

Break time
:

End time
:

APPENDIX D – POST TEST EVAULATION FORM

Post Test Evaluation Form

Difficulty

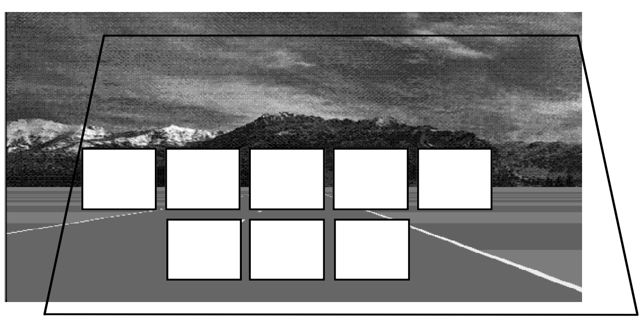
As you may have noticed during the study, the roads consisted of straight sections and curves of two difficulties.

How difficult was it to read the names and click the corresponding switch while driving in each of these 3 sections? (draw a vertical line on each of the scales.)

	extremely easy	extremely difficult
(1) straight	├	┤
(2) moderate curve	├	┤
(3) sharp curve	├	┤

Preferred location of HUD

Here are 8 locations where messages appeared on the HUD. Rank the locations from best (1) to worst (8). If two locations were similar (but not more than two), you may give both the same rank. Consider how easy it was to detect the message, to read it, and its impact on driving.



If your next car had a HUD which displayed names momentarily on the windshield whenever your cell phone or pager received a message, where would you prefer the HUD to be located? (Circle the best location.)

How realistic was the simulator?

	very artificial	very real
(1) Steering	|———|
(2) Graphics (road scene)	|———|
(3) Sound (engine and road sounds)	|———|
(4) Vibration	|———|

How comfortable did you find the finger switches?

	very uncomfortable	very comfortable
(1) Finger switch	|———|

Description of the Response Process

Describe how you responded to the task of reading male and female names while driving (from the time the message was displayed, to when you responded).

3 Where did you look while driving? (looked at the road and waited to see something, occasionally searched the HUD for new messages…)

____

____

4 How fast did you respond when messages appeared? (immediately or only after checking the vehicle direction?)

____

5 How many times did you look at the message to get the answer?

____

6 Where were you looking when you thought which finger switch to click?

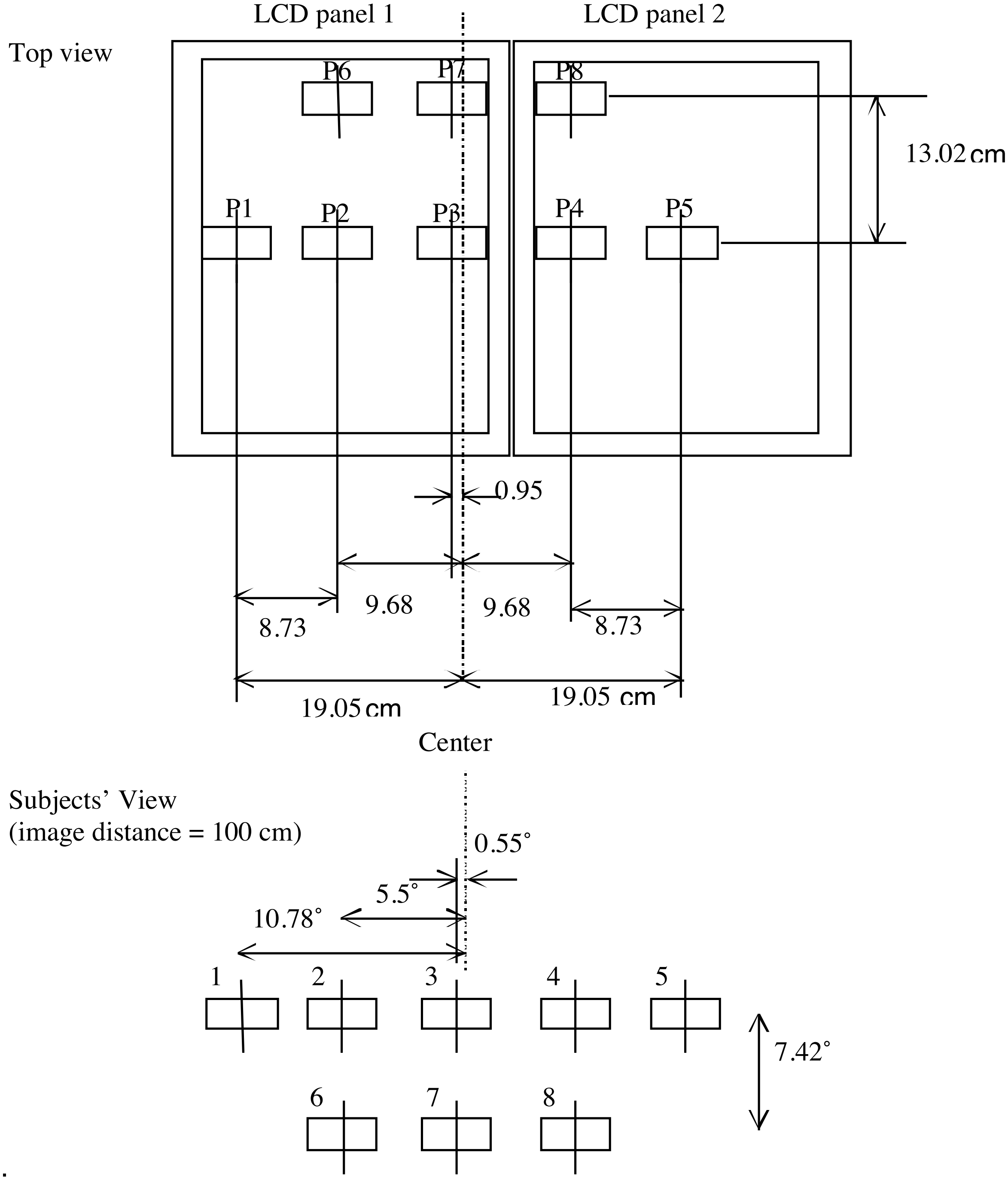
____

Any other comments about this study? (please think of at least 2 …)

____

APPENDIX E – HUD POSITIONS

Eight HUD positions were implemented in this study. Two LCD flat panel displays were mounted on the dashboard of the simulator vehicle and reflected off a thin Plexiglas. The sizes and distances of the distinct positions were chosen to optimize space requirements of the two displays, while maintaining the symmetry as much as possible.



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