Detecting and Reading Text on HUDs: Effects of Driving Workload and Message Location

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ABSTRACT

This paper describes the second in a series of studies to identify best locations for presenting information on an automotive head-up display (HUD). A total of 16 participants (8 under age 30, 8 over age 65) drove a simulator (at 3 controlled levels of driving workload) while responding to messages appearing at 8 locations on a HUD. Depending on the condition, participants either pressed buttons to indicate the gender (male, female) of a first name shown on the HUD or detected the appearance of a scrambled name. The overall pattern of the results was generally similar for both young and old drivers, though the driving performance of older men was better (less variable) than other age-gender groups. Their responses to HUD messages, however, were slower, and they committed more errors.

In contrast to the prior study, detection time was not significantly affected by HUD position. However, mean responses times for the reading task were significantly affected (1100 ms for center positions straight ahead versus 1250 ms for outer positions 10 degrees to either side).

Across the limited range of driving workload levels explored, detection time increased by as much as 140 ms (25%) and information was more likely to be missed in the higher workload condition. Mean response time in the reading condition increased by 90 ms (7%). Driving performance was only degraded when the HUD appeared at the center position. The position most preferred by participants was at eye level, 5 degrees to the right of the center, with the center and 5 degrees to the left of the center as alternatives.

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.

INTRODUCTION

As the number of in-vehicle telematics applications has grown, so too have demands for space for displays. However, the space available on the instrument panel for displaying information associated with driver operated in-vehicle systems is fixed, so alternative locations are being explored. Furthermore, adding displays to the instrument panel may not be appropriate, as the increased in-vehicle visual demands may lead drivers to spend less time looking at the road. One option being explored is to place critical, time-sensitive information on a head-up display (HUD). There has been extensive research on automotive HUDs and related topics (e.g. (1,2,3)).

An initial step in designing a HUD is prioritizing the information that could be displayed. Thoughts on potential selection criteria appear in the report on which this paper was based (4). A standard for those selection criteria is being developed by the International Standards Organization under the auspices of Technical Committee 22, Subcommittee 13, Working Group 8 (Ergonomics of Road Vehicles, Transport Information and Control Systems).

Once the information to appear on a HUD has been determined, a location for each item needs to be selected. The lack of data comparing a wide range of locations led to the prior study (5,6). In that experiment, 24 participants sat in a driving simulator and watched a video tape of a real expressway. (They did not actually drive.) To encourage participants to scan the road-scene as they would while driving, participants pressed a button when various events occurred (e.g., the brake lights of the lead vehicle illuminated, certain types of signs were visible). 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 detection (response) times varied from approximately 840 to 1390 ms, with the fastest response time occurring to warnings presented 5 degrees to the right of center. The detection probability of 12 of the 15 locations within a 6 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. Although there was no overwhelming consensus for a single location, the most preferred location was 5 degrees to the right of the center and that location generally led to the shortest detection times and fewest errors.

As a follow-on study, this experiment was conducted to explore how detection times, response times, errors, driving performance, and subjective preference might depend on the location of the message, the driving workload, and the nature of the driving simulation.

TEST PLAN

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. Members of the public were recruited via an advertisement in the local newspaper and from the UMTRI participant database. Participants were paid $35 for performing the study. They reported driving a mean of 11,800 miles per year, close to the U.S. mean of 13,000 miles per year [http://www.fhwa.dot.gov/ohim/hs97/nptsdata.htm]. All participants had far visual acuity of 20/40 or better, as required by Michigan State law for a driver's license, and there were no noteworthy health problems.

This experiment was conducted using the UMTRI Driver Interface Research Simulator (software version 7.1.3), a medium-fidelity, low-cost, driving simulator based on a network of Macintosh computers [http://www.umich.edu/~driving/sim.html]. 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.

A simulated windshield (an acrylic sheet) was placed slightly ahead of the normal windshield location. Reflected from it, participants were able to see images generated by 2 Liquid Crystal Display (LCD) panels placed on top of the dashboard. The focal distance was approximately 1 meter. Letters had a visual angle of 11 milliradians and could be easily read by all drivers. Text presented included common first names for Americans (as determined by the 1990 U.S. census, [www.babynamer.com]) and scrambled versions of those names to test detection without reading. Names appeared at the 8 locations shown in Figure 1. On any given trial, a randomly selected name would appear on a randomly selected location. These 8 locations were the best of 15 locations (3 rows of 5 columns) explored in the previous experiment. Excluded were the top row (about 5 degrees above the horizon) and two extreme locations on the bottom row (5 degrees below the horizon). The two tasks described were intended to represent the detection and identification of brief text warnings and icons.

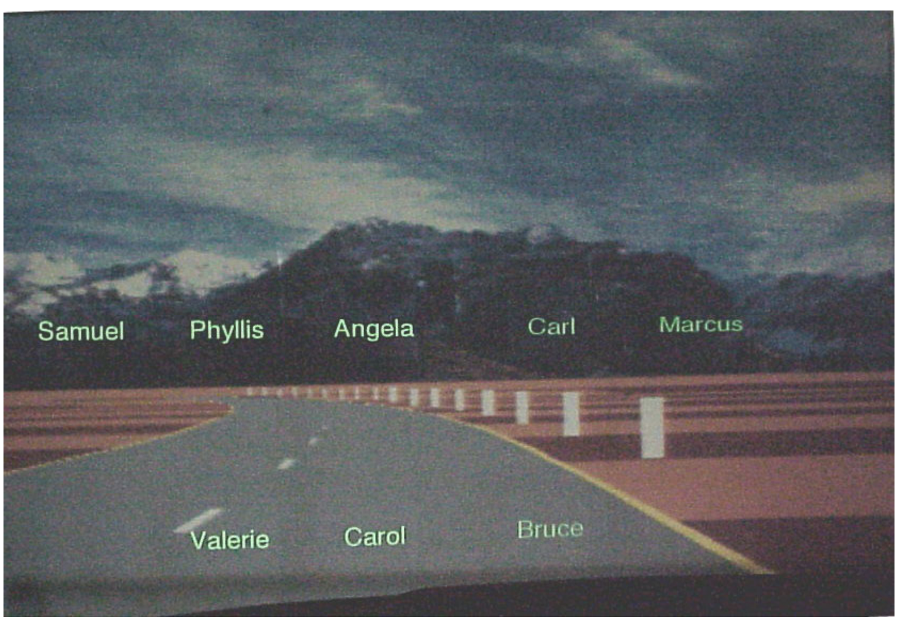

Figure 1. HUD Locations Examined.

The simulated roads were designed to impose 3 levels of workload by varying road curvature (straight section, moderate curve (radius of 582 m=3 degrees of curvature), and sharp curve (radius of 194 m=9 degrees of curvature)). The order of curves was counterbalanced across participants. The geometric characteristics of roads were chosen based on a study by Tsimhoni and Green (7), in which a linear relationship was found between the mean visual demand and the reciprocal of curve radius. They found that the visual demand within curves was greatest at the beginning of curves and decreased to a stable level after approximately 150 m from its beginning. Therefore, in this experiment, the HUD tasks began at least 200 m after the beginning of curves and the curves were extended to provide constant visual demand values (approximately 2 minutes) necessary for the experiment. The sharpest curve, 540 degrees long, could only be built in a virtual environment.

After completing a biographical form, consent form, and a vision test, participants sat in the driving simulator. Their position was adjusted to place them at a focal distance of 1 meter from the HUD image. Tasks examined included detection and reading. In the detection task, participants pressed a switch, mounted on the index finger, when the name (scrambled in this task) appeared. In the reading task, participants pressed 1 of 2 finger switches to identify if the name shown was male or female. (Note: Gender ambiguous names, such as Chris, were not used.) The conditions were ordered as follows: detection (practice then test), driving (practice then test), detection while driving (practice then test), reading (practice then test), reading while driving (practice then test), break, reading while driving, reading, and detection. Subsequently, participants completed a post-test evaluation in which they rated the difficulty of tasks and discussed what they did. The experiment required approximately 2 hours to complete.

RESULTS

Response Time

Prior to analysis, the response time data were log transformed to provide a better fit to the normal distribution, a requirement of Analysis of Variance (ANOVA). Further analysis showed that one participant had far more errors than the others in his age group and the video tape showed that he was very sleepy. Therefore, the primary analysis was completed without the data from this participant. Omitting this participant led to the same conclusions, but they were slightly stronger.

In the ANOVA, 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 (male, female), and the participant nested within age and sex. Overall, there were no statistically significant differences in location in the detection task ($p=0.21$) though significant differences related to eccentricity ($p=0.0002$) were found for the reading task. (See Figure 2.) Readers should bear in mind that the selected locations were the "best" of those examined in a previous experiment, so large differences were not expected.

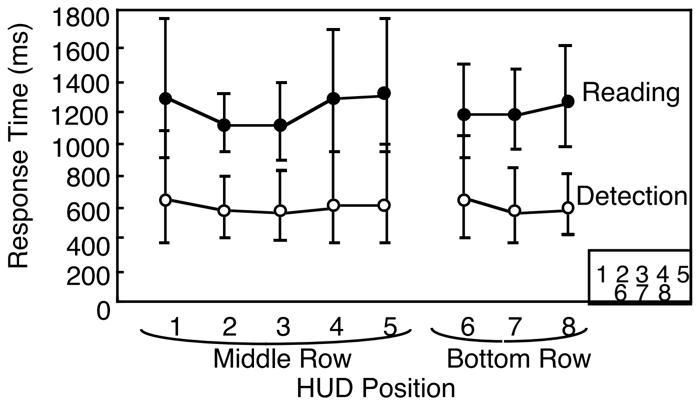

Figure 2. Detection time and reading time as a function of HUD position

As shown in Figure 3, response time for both the detection and reading tasks significantly increased across the limited range of driving workload explored (p=0.0002). Mean detection time increased by as much as 140 ms (25%), while mean response time in the reading task increased by 90 ms (7%).

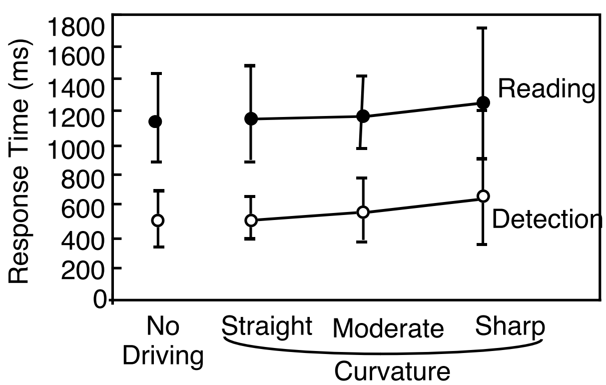

Figure 3. Detection time and reading time as a function of driving workload

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).

Errors and Misses

Driving workload had no systematic effect on the percentage of incorrect responses for both tasks. However, the percentage of missed responses (those not within 6 seconds) increased sharply with curvature (Figure 4). Most likely, this reflects participants being unable to detect peripheral targets, such as when following a sharp left curve (and looking to the left) when a target appears on the far right.

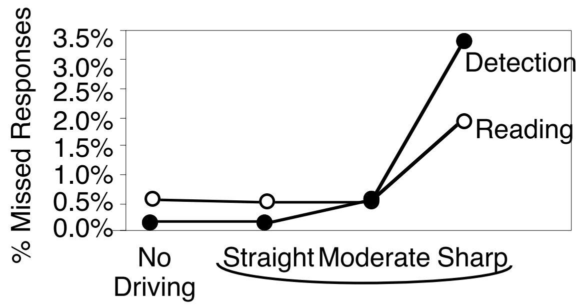

Figure 4. Missed responses to HUD messages

Driving Performance

Differences in driving performance due to HUD message location were small, with the standard deviation of lane position changing by about 5 percent (for the detection task) and 10 percent for the reading task (over the baseline condition of no secondary task).

However, there were differences due to workload, with the standard deviation of lane position increasing from 8 cm for straight sections to 9 cm for moderate curves, and 15 cm for sharp curves (88 percent increase over straight).

Further examination of the data revealed complex tradeoffs. In general, older participants tended to emphasize driving over the response time task, whereas younger participants gave the response time tasks higher priority (and therefore did not drive as well as older participants).

Subjective Evaluation

Table 1 shows the mean ranks (1=best, 8=worst) for each message location. The preferred location was just to the right of center. Preferences for caller ID and pager message indicators generally favored the center and right locations of the middle row.

Table 1. Preferences for Message Location

	Left		Center	Right	
	-10 deg.	-5 deg.	0 deg	5 deg.	10 deg.
Middle row (0 deg)	**6.2 (worst)**	**3.5**	**3.1**	**3.0 (best)**	**5.0**
Bottom row (-5 deg)		**5.7**	**4.2**	**5.3**	

CONCLUSIONS

The effect of HUD message location

In contrast to the wide range of locations explored in the prior experiment, this experiment only explored reasonably good candidates. Therefore, there were no significant differences between locations for the detection task. In the reading task, however, significant differences between locations were found. Response times generally increased with the angle from straight-ahead.

Differences in driving performance due to HUD message location were small, with the standard deviation of lane position changing by about 5 percent (for the detection task) and 10 percent for the reading task (over the baseline condition of no secondary task).

Participants thought that the three center positions in the middle row were better than the other positions. The most preferred position was at eye level, 5 degrees to the right of the center, with the center and 5 degrees to the left of center as alternatives.

The effect of driving workload

Increasing driving workload increased detection time by 140 ms (25%) and response time in the name reading task by 90 ms (7%). 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.

Detection time on sharper curves (675 ms) was slower than on straight sections (545 ms). The effect of driving workload on the reading task was similar in magnitude to 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. For sharp curves, averaging across all locations, over 3 percent of all HUD messages were not detected within 6 seconds of message presentation. Thus, designers cannot be certain that warnings requiring an immediate driver response will always be detected in time.

Driving was more variable in sharp curves than in moderate curves or straight sections (standard deviation of lateral position 0.15 m and 0.08, respectively). Interestingly, the driving performance of younger drivers (as measured by the standard deviation of lane position) was worse than that for older drivers, opposite of what was expected. It appears that older drivers emphasized the driving task, while younger drivers gave relatively more priority to the HUD response time tasks.

In summary, the central location and other locations within 5 degrees of straight ahead gave the best overall 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. Overall, these data provide interesting insights into the effects of driving workload (visual demand) and the driver's task in responding to HUD-based messages. Of interest is the driver's behavior in more complex driving situations (with traffic) while making more complex decisions (e.g., involving navigation displays or longer text messages).

ACKNOWLEDGEMENT

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REFERENCES

1. Weintraub, D.J., and Ensing, M. (1992). Human Factors Issues in Head-Up Display Design: The book of HUD (SOAR 92-2), Wright-Patterson AFB, OH: CSERIAC.

2. Fukano, J., Okabayashi, S., Sakata, M., and Hatada, T. (1994). Automotive Head-Up Displays for Navigation Use, Proceedings of the 14th International Technical Conference on Enhanced Safety of Vehicles, Washington, D.C.: National Highway Traffic Safety Administration, 306-314.

3. Kiefer, R. and Gellatly, A. (1996). Quantifying the Consequences of the “Eyes-On-Road” Benefit Attributed to Head-Up Displays (SAE Paper 960946), Warrendale, PA: Society of Automotive Engineers.

4. Tsimhoni, O., Watanabe, H., Green, P., and Friedman, D. (2000). Display of Short Text Messages on Automotive HUDs: Effects of Driving Workload and Message Location (Technical Report UMTRI-00-13), Ann Arbor, MI: University of Michigan Transportation Research Institute.

5. Watanabe, H., Yoo, H., Tsimhoni, O, and Green, P. (1999). The Effect of HUD Warning Location on Driver Responses, paper presented at the 1999 ITS World Congress (CD-ROM).

6. Yoo, H., Tsimhoni, O., Watanabe, H., Green, P. and Shah, R. (1999). Display of HUD Warnings to Drivers: Determining an Optimal Location, (Technical Report UMTRI-99-5, ITS RCE report #939423), Ann Arbor, MI: University of Michigan Transportation Research Institute.

7. Tsimhoni, O. and Green, P. (1999). Visual Demand of Driving Curves Determined by Visual Occlusion, paper presented at the Vision in Vehicles 8 Conference.