Perspective in Orientation/Navigation Displays: A Human Factors Test

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Abstract

Twelve drivers (6 ages 18-30, 6 over 65) participated in an experiment. While seated in a vehicle mockup, they were shown slides of residential intersections photographed from the driver's viewpoint. Simultaneously, drivers saw slides of a navigation display. Drivers indicated if the two images were for the same or different type of intersection (cross, Y, T, etc.).

The response times indicated that Head-Up-Display-mounted displays were better than console-mounted displays (1524 versus 1630 ms), that aerial views were slightly better than plan views (1501 versus 1523 ms) and much better than perspective views (1706 ms). Finally, responses to displays where the roads were shown as solid objects were more rapid than to those shown as outlines (1557 versus 1597 ms). Error and preference data supported these results.

The results from this experiment should be validated with on-road data.

Introduction

There is a growing body of literature on the design of safe and easy to use driver interfaces for navigation systems (Davis and Schmandt, 1989; Dingus, Antin, Hulse, and Wierwille, 1989; Streeter, Vitello, and Wonsiewicz, 1985; Walker, Alicandri, Sedney, and Roberts, 1991, Green, 1992). While there is still debate if the information should be presented visually or auditorially or both, it is evident that complex map displays are not desired.

Typically visual displays show scalable maps with the most detailed view presenting individual intersections. For route guidance, these single-intersection displays can be particularly useful. There are many questions, however, concerning how to format the display. Most systems (e.g., TravTek) represent the world as a plan view, exactly what one would see on a map. This representation allows the viewer to readily classify the geometry of the road network since it matches the driver's internal representation of the world. The internal representation is an abstract description of linked sets of cross intersections, T intersections, cloverleafs, etc.

But looking out a windshield gives a perspective view of the world, not a plan view. For orientation, drivers must match what they see on the navigation display with the outside scene. This suggests representing the world in perspective on the navigation display. If plan and perspective views have advantages, then a compromise representation containing aspects of both (for example, the aerial view from a very low flying airplane) could be even better. Alternatively, an aerial display could be a poor choice because it contains the weaknesses of both plan and perspective displays. Further, the advantage of one format over another may depend on the location of the navigation display relative to the road scene. If the visual angle between the two is small, as for a Head-Up Display (HUD), a template match should be easy, thus favoring a perspective view. When the angle is large, there might be time to abstract the road geometry from the scene, favoring a plan view.

Since these issues have not been considered in the literature and could not be resolved by argument, an experiment was conducted (Williams and Green, 1992). This paper summarizes the results obtained. Of specific interest were:

1. How long does it take a driver to interpret an orientation display
   a. when it is on a Head-Up Display (HUD) versus on the instrument panel (IP)?
   b. as a function of the navigation display viewpoint (plan, perspective, aerial)?
   c. as a function of the road graphic design (solid or outline)?
2. Which displays do drivers prefer?
3. Do the preference and performance data agree?
4. What is the sequence of driver eye fixations in making such decisions?
5. What are typical eye fixation times?

The first three questions are answered here. Readers interested in the eye fixation data should see the associated technical report (Williams and Green, 1992). Readers interested in how these displays evolved and other matters related to this project should see Green, Serafin, Williams, and Paelke (1991), Green, Williams, Serafin, and Paelke (1991), Green and Brand (1992), and Paelke and Green (1992).

Test Activities and Their Sequence

After completing a biographical form, answering questions about their use of maps, and having their vision tested, participants were seated in an A-to-B pillar mock-up of a 1985 Chrysler Laser. The test protocol was then explained. On each trial a slide was shown on a retroreflective wall about 7.3 m in front of them. At the same time, a slide of a navigation system display (or a geometric shape in practice trials) was shown either on the instrument panel or where a HUD would be located. The display location was fixed for each block. The driver's task was to examine the two images and press either a same or different key on the center console. After a delay of three seconds, the projector displayed the next randomly-ordered slide.

Each participant responded to fifteen trial blocks. The first 2 blocks of 56 trials each were for practice. Participants were shown slides of 7 geometric shapes (squares, circles, etc.) on the wall and at 1 of the 2 test locations (HUD or IP). The probability of 'same' and 'different' responses was equal. This task helped participants learn the same-different response time task without giving them specific practice with the stimuli of interest.

Subsequently, participants responded to six blocks of test trials. For those blocks the location was fixed (HUD or IP). Across blocks the View (perspective, aerial, plan) and Road Format (solid, outline) were varied in a counterbalanced order.

On each trial, participants were shown 1 of 15 randomly-ordered life-size images of intersections and, simultaneously, a slide of a navigation display. As before, they responded 'same' or 'different' by pressing a key. Within each test block each slide appeared at least four times, twice as a 'same' response and twice as 'different.' For the different trials, navigation displays shown were those most likely to be confused with the road scene. Thus, the number of trials per block was at least 60 (4 x 15). All trials with exceptionally fast responses (under 400 ms) or slow responses (over 4 seconds) were automatically repeated at the end of each block. Error trials were also repeated. Consequently, each block contained an equal number of correct responses with reasonable times.

After a break, participants were given an additional practice block of 56 trials involving responses to geometric shapes at the second location followed by six blocks of test trials at that location. Location order was counterbalanced across participants.

After completing the response time portion of the experiment, participants rated the 12 designs from best to worst. Sessions averaged 1 and 3/4 hours per person. On average, each participant responded to just under 1000 trials.

Test Equipment and Materials

The slides of intersections shown in test blocks were photographed from roughly the driver's eye position in a car. There were five types of intersections shown (cross, Y, T, T-right, and T-left) with three examples of each type. Most were of residential areas in or near Ann Arbor, Michigan, photographed in the fall. For the sake of simplicity, expressway interchanges were not considered. Examples of navigation display slides are shown in Figures 1, 2, and 3. (The actual displays were in color.) The displays were highly legible with the IP navigation displays having character heights of approximately 1/4 inch.

Three random-access slide projectors (1 Mast System 2, 2 Kodak Ektagraphic RA-960s), fitted with Lafayette external shutters and custom controllers presented the slides. An IBM XT computer fitted with a custom interface/timing board controlled the projectors. Input from participants was obtained from a custom keyboard with two piano-like keys mounted above microswitches. The keyboard was within easy reach on the center console. All timing was to the nearest millisecond.

In addition, all sessions were videotaped. An RCA model TC1030/H10 low-light level video camera aimed at the participant's face recorded eye motions. A JVC S100U color camera, along with a time/date generator (Thalner TD426P), special effects generator (JVC KM-1200), and a VCR (Panasonic AG-6200) time stamped, mixed, and recorded the road and navigation displays shown on each trial.

Other miscellaneous equipment used included a Titmus Vision Tester model OV-7M. A Photo Research Spectra Pritchard digital Spot Photometer model PR-1980A-CD was used to set display lighting levels.

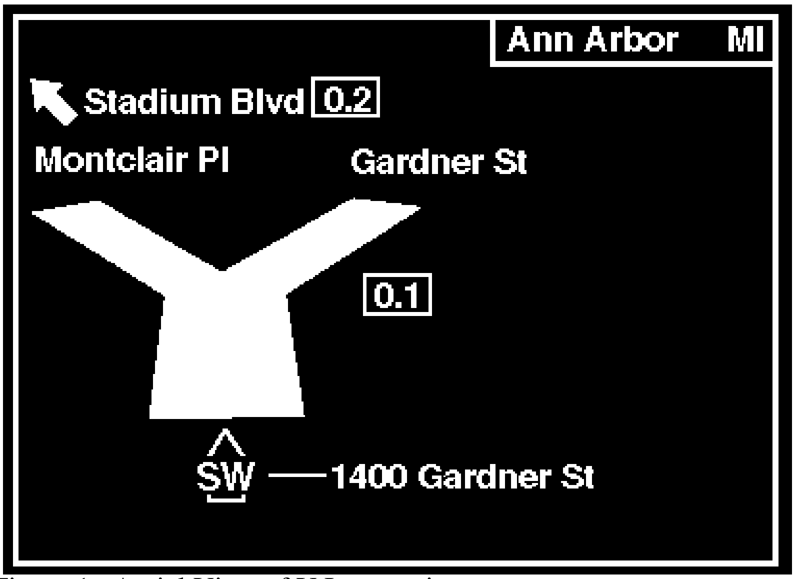

Figure 1. Aerial View of Y Intersection.

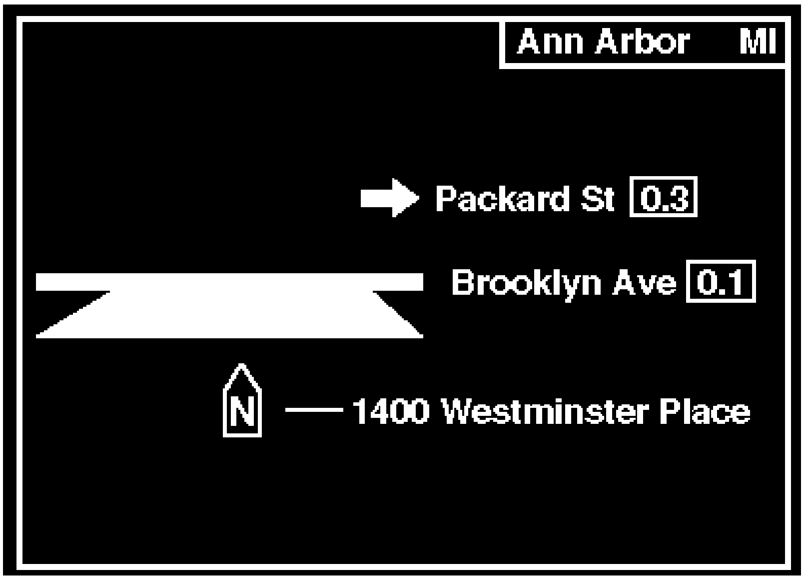

Figure 2. Perspective View of T Intersection.

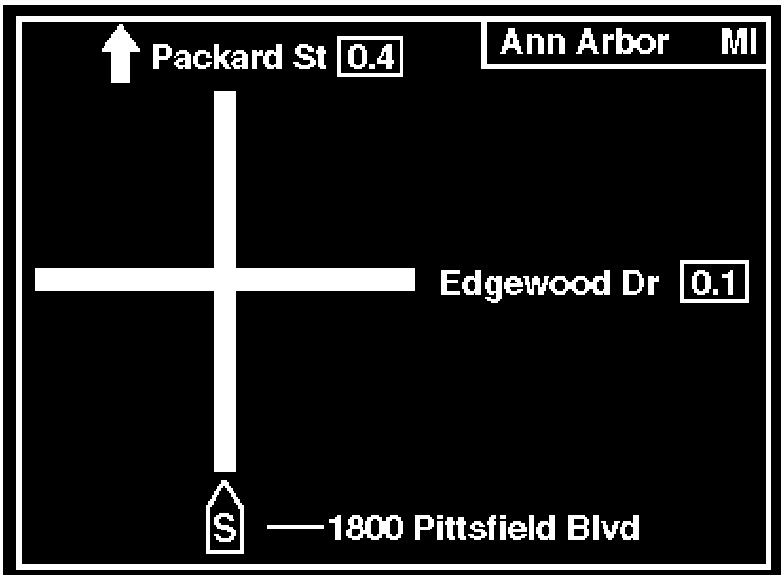

Figure 3. Plan View of Cross Intersection.

Test Participants

Participating were 12 licensed drivers, 6 young (18-30) and 6 old (65 or older). Within each age bracket there were three men and three women. The participants were recruited using lists from previous UMTRI studies. They were paid $15 for their participation.

The mean age of the young subjects was 22 and of the old subjects was 69. Corrected visual acuity for the young subjects ranged from 20/13 to 20/22. For the old subjects it ranged from 20/18 to 20/100. Participants drove 2000 to 25,000 miles per year with a mean of 9900 miles. Only one person had ever driven a car with a HUD. In identifying their comfort with maps, eight stated they were very comfortable and four stated they were moderately comfortable.

Results

Some 11,848 key presses were recorded, of which 8,640 involved correct responses to slides on test trials within the time deadlines. The percentage of trials repeated varied sharply with age, 2.8% for young drivers, 12.4% for older drivers. For older drivers, a large fraction of those trials involved correct responses that took longer than the maximum response time. A maximum time of 5500 milliseconds and a minimum of 500 should be considered in future studies.

Error rates were fairly low, varying from just 1.5 to 5.5% for younger drivers and 5.5 to 14.3% for older drivers. For the display variables, there was almost no difference in errors due to location (both about 6%). There were, however, large differences due to View (aerial-3.4%, plan-4.5%, perspective-9.9%), but only slight differences due to Road Format (solid-5.5%, outline-6.6%).

The primary analysis of the data was an 11-factor ANOVA. Included were 3 participant-related factors--Sex, Age, and Subjects nested within Age and Sex, 5 display factors--Location, View, Road Format, Type of Intersection, and Intersection Example, and 3 protocol-related factors--Block Number, Response Type (Same or Different), and Repetition of slides in blocks.

Because the full model would yield over 500 terms, most of which are high order interactions that are uninterpretable, all interactions involving three factors or more, and some involving three factors that were thought to be unimportant or insignificant, were pooled.

Of the factors related to people (Sex, Age, and Subjects nested with Age and Sex), all were very highly significant ($p<.001$). Table 1 shows the means. Differences due to age were very large, about 600 ms with older drivers being 50% slower in responding. Differences due to sex were also large, with men being about 10% (186 ms) faster. The range of response times within Age-Sex categories was 200-300 ms, though it was 800 ms for the Older Women category. The interaction between Age and Sex was not significant.

Table 1. Mean Response Times (ms) by Participant.

	Sex		
Age	Men	Women	Mean
Young	1148 1398 875	1391 1322 1525	1276
Mean	1140	1412	
Old	1945 1758 1777	2408 1755 1618	1877
Mean	1826	1927	
Grand mean	1483	1669	

Test Protocol factors--Blocks, Response Type (same or different), Repetitions--were very highly significant (p<.001). Response times to 'sames' were faster than 'differents' (1537 versus 1616 ms), as is typical. Just as performance improved across blocks, likewise it improved within blocks for the repetition of slides (1631 versus 1522 ms).

Regarding displays, the effects of Location and View were very highly significant (p<.001). The effect of Road Format was also significant, but at a lower level (p<.05). Response times to HUD displays were about 100 ms less than IP displays (1524 versus 1630 ms). Response times to aerial views (1501 ms) were less than those to plan views (1523 ms) and considerably less than those to perspective views (1706 ms). Interestingly, to date, all map format navigation systems have used plan views. While the perspective view is a direct analog of the scene, the authors believe drivers did not respond well to it because many of the key details (e.g., cross streets) were thinner and more difficult to see in perspective.

Driver response times for navigation displays with roads shown as solid lines were less than those in outline form (1557 versus 1597 ms).

Of these display factors, only the interaction of Location with Road Format approached significance (p=.12), with the use of outline road images being relatively more detrimental on the instrument panel (1595 versus 1664 ms) than on the HUD (1519 versus 1528 ms).

Also noted was a very highly significant interaction between Sex and Location (p<.001) and a significant interaction between Age and Location (p<.05). Apparently, men did relatively better in using the HUD display (HUD=1415 ms, IP=1552 ms) than did women (HUD=1632 ms, IP=1707 ms). For Age, the HUD location was relatively more beneficial to older drivers (HUD=1807 ms, IP=1945 ms) than for younger drivers (HUD=1240 ms, IP=1312 ms).

As one would expect, there were very highly significant differences between intersection types and intersections within type (both p<.001). In spite of these differences, there were no interactions with display factors (Location, View, Road Format), suggesting the selection of intersections was appropriate.

The results from the ranking task were quite similar to the response time task. The correlation of the mean ranks and mean response times was 0.948, significant at p<.001. Following is a table showing the 12 interfaces examined, ranked by response time along with the associated mean rankings.

Table 2. Mean Response Times and Ranks.

System	RT(ms)	Mean Rank
Aerial Outline HUD	1443	4.17
Plan Solid HUD	1447	3.42
Aerial Solid HUD	1459	4.17
Plan Outline HUD	1497	3.50
Plan Solid IP	1524	5.75
Aerial Solid IP	1547	6.42
Aerial Outline IP	1557	6.25
Plan Outline IP	1623	5.83
Perspective Outline HUD	1646	9.25
Perspective Solid HUD	1651	7.92
Perspective Solid IP	1714	10.17
Perspective Outline IP	1811	11.17

Conclusions

This experiment provided an opportunity to examine a laboratory method for evaluating orientation displays. The method was able to identify differences among display designs, some of them subtle (e.g., solid versus outline roads) using a relatively small number of subjects. There were remarkably few interactions, suggesting this procedure is quite robust. Further, this method employed high fidelity road scenes, something that would be extremely difficult to simulate at low cost using current computer technology.

Additional data should be collected for freeway interchanges. That experiment should be conducted using a slightly larger range of acceptable response times. Validation of the results of this experiment with real world data is also desired.

According to these data the navigation display should be an aerial view presented on a HUD. For that combination, showing the roads on the display as outline or solid has little effect on performance. If it is technically difficult to construct the aerial view graphics, a plan view can be used, as the differences are slight. As demonstrated at the 1991 VNIS meeting, use of aerial views is being considered for the ADVANCE project underway in the Chicago area, but there are no published data to support the use of aerial displays other than the information in this paper. The use of aerial views should be explored further.

It is evident from this data, however, that a perspective view should not be used. These conclusions were supported by both the driver performance and the preference data. Poor performance resulted from the key details of the upcoming intersection being too small. It is believed that this weakness is inherent in the design and cannot be corrected. It would be interesting to see if this weakness is also present in full windshield HUDs in which navigation information is superimposed on the outside world.

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