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Turn-by-Turn Displays versus Electronic Maps: An On-the-Road Comparison of Driver Glance Behavior

Aaron Brooks
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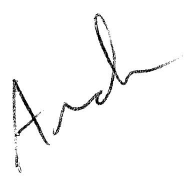
HUMAN FACTORS

UMTRI The University of Michigan Transportation Research Institute



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16. Abstract

This report is the fifth in a series that examines the use of electronic navigation displays while driving. Sixteen subjects (ages 18 to 30 and 65+) drove a test vehicle on freeways, city streets, and residential streets to six specified destinations in a fixed order. The vehicle was equipped with two Magellan PathMaster navigation units which bracketed the steering wheel, one showing turn-by-turn guidance and one showing a route map. Glances to each display were examined.

The average number of glances per subject was 291. Over the 30.7-mile route, each subject averaged 9.5 total glances per mile. Overall, the turn-by-turn display was looked at 3.75 times more often than the route map display, with a higher ratio when the turn-by-turn display was on the right side of the steering wheel than when it was on the left.

For the turn-by-turn display, a burst of glances usually occurred at the beginning of the segment followed by a lower steady rate for the rest of the segment. Glances to the route map display were relatively uniform throughout each of the segments. Also, glance bursts usually occurred when the navigation systems beeped or spoke.

The glance rate (total glances per mile per subject) decreased as segment length increased and was much higher for city segments than for freeway segments (10.8 and 6.9 glances per mile per subject, respectively).

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Turn-by-Turn Displays versus Electronic Maps: An On-the-Road Comparison of Driver Glance Behavior

UMTRI HUMAN FACTORS

UMTRI Technical Report 98-37, January 1999
Aaron Brooks, Christopher Nowakowski, and Paul Green

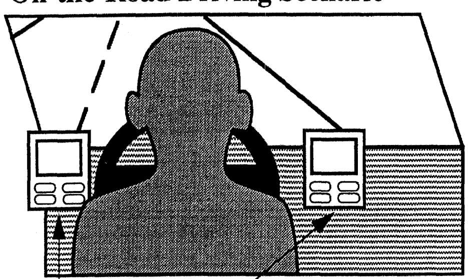
University of Michigan
Ann Arbor, Michigan, USA

1 ISSUES

1. Which display was glanced at more, the turn-by-turn or route map?
2. What factors affected glances to the turn-by-turn and route map displays?
3. When did display glances occur along the road segments?

2 METHOD

On-the-Road Driving Scenario



Magellan PathMaster navigation units (2)

Subjects

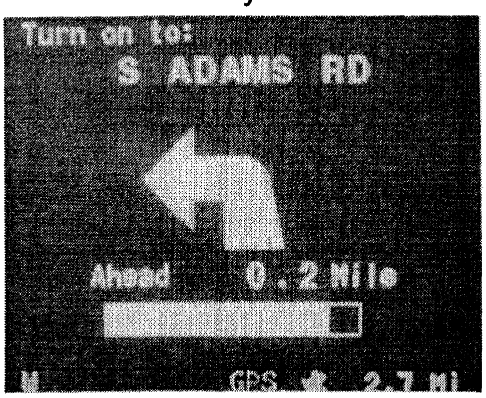
	Left	Right	Women	Men
Young (18-30)	map	turn	**2**	**2**
	turn	map	**2**	**2**
Older (65+)	map	turn	**2**	**2**
	turn	map	**2**	**2**

Protocol

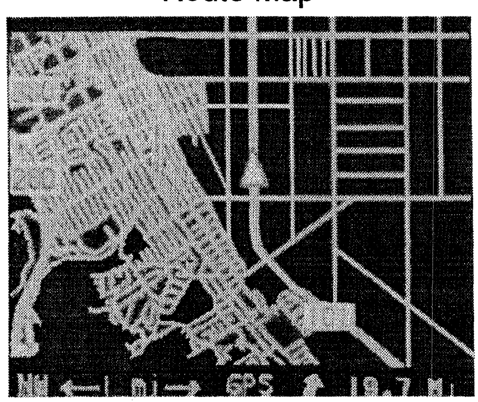
- Experimenter remotely enters destination from back seat
- Subject drives to destination using both displays
- Repeat for two practice destinations and six test destinations (total of 37 miles and 45 turns)

Sample Display Screens

Turn-by-Turn



Route Map

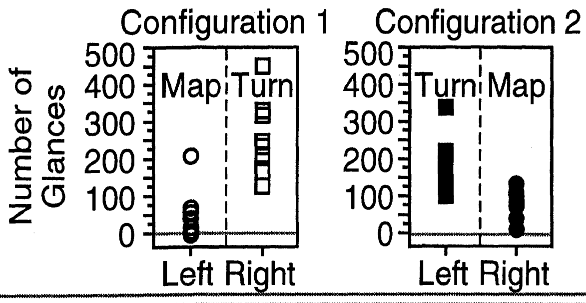


(each 80% of actual size)

4 RESULTS

Issue 1 - Which display was glanced at most?

Overall display and location effects



- Turn-by-turn display glanced at 3.75 times more often than route map display
- Both displays glanced at more when on the right side of the steering wheel

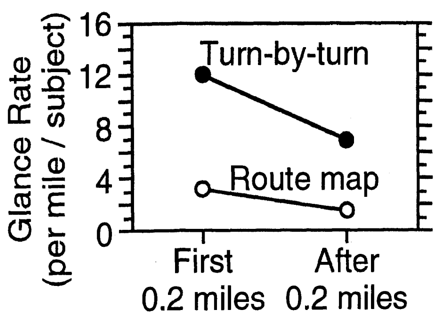
Issue 2 - What factors affected display glances?

Age and gender effects

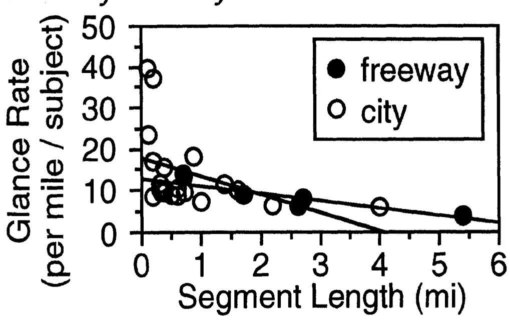
- Age and gender affected glances
  - young women similar to older men
  - young men similar to older women
- Average of 291 glances per subject (9.5 glances per mile over the 30.7-mile route)

Issue 3 - When did display glances occur?

Glance rate summaries for freeway and city roads



- **Turn-by-turn display**
  - Burst of glances at segment start
  - Steady glance rate over remainder of segment, with slight increases when system spoke
- **Route map display**
  - Low uniform glance distribution



- Glance rate decreased as segment length increased
- Road type affected glance rate
  - City: 10.8 glances/mile/subject
  - Freeway: 6.9 glances/mile/subject

5 CONCLUSIONS

- Drivers relied primarily on the turn-by-turn display for navigation, not the route map.
- Glance rate was highest at the segment start, within 0.2 miles from the previous turn.
- Glance rate depended on the type of road being driven and the road segment length (7 to 11 total glances per mile for each subject was typical).
- In the U.S., navigation displays should be located to the right of the steering wheel, if possible.

PREFACE

This research was funded by the University of Michigan Intelligent Transportation Systems (ITS) Research Center for Excellence. The program is a consortium of companies and government agencies, working with the University, whose goal is to advance ITS research and implementation.

The current sponsors are:

- Ann Arbor Transit Authority
- Automobile Association of America (AAA)
- Chrysler Corporation
- Federal Highway Administration (FHWA)
- Ford Motor Company
- General Motors Corporation
- Hewlett Packard
- Michigan Department of Transportation
- Nissan Motors
- NOVA Laboratories
- Orbital Sciences
- Road Commission of Oakland County
- Ryder Trucks
- Siemens Automotive
- Toyota Motor Corporation

We would like to thank the lead corporate sponsor for this project, Toyota Motor Corporation, for their support. Originally Cale Hodder, and now Jim Bauer (both from Toyota), have served as project technical monitors. We would also like to thank the Magellan Division of Orbital Sciences Corporation for loaning two navigation systems for this project and for custom modifications to allow remote input of device settings.

Electronic maps are commonplace in automotive navigation systems in Japan, and soon will be common in the United States and Europe. To make such maps safe and easy to use while driving, it is important to know how engineering, individual, and task factors affect reading time, and how reading time can be minimized. The more time drivers spend looking in the vehicle, the less time they spend looking at the road, increasing the opportunity for crashes. Given the almost complete absence of literature on the time to read maps prior to this project, two specific issues were addressed.

> Issue 1: How long does it take to read an electronic local map as a function of label size and orientation, the number of streets shown, the percentage of streets labeled, display location, and the driver's task?

> Issue 2: When do drivers desire area maps instead of turn (intersection) displays?

These issues were examined in the five reports summarized on the next page.

Green, P. (1999). Reading Electronic Area Maps: An Annotated Bibliography (Technical Report UMTRI-98-38) (in preparation).

> This report contains a collection of summaries generated by the author. Primary articles concerned performance differences in reading street names due to type size, how people follow directions using street maps, etc. There were no articles in the literature that methodically considered how factors related to street-map design affect task completion time. Secondary articles considered color coding, symbols for tourist information, and so forth.

Brooks, A., Lenneman, J., George-Maletta, K., Hunter, D.R., and Green, P. (1999). Preliminary Examinations of the Time to Read Electronic Maps: The Effects of Text and Graphic Characteristics (Technical Report UMTRI-98-36) (in preparation).

> This report summarizes the initial series of simulator experiments concerning reading electronic maps. Included were efforts to identify representative maps and street names for testing and a pilot experiment concerning the subjective legibility of various map typefaces. In the main experiment, the time to read the electronic maps was found as a function of text size, the number of streets, text orientation, and gridness.

Brooks, A. and Green, P. (1998). Map Design: A Simulator Evaluation of the Factors Affecting the Time to Read Electronic Navigation Displays (Technical Report UMTRI-98-7).

> This report describes a simulator experiment that was an extension of the first main experiment. This extension examined situations when only some of the street names were labeled, small text sizes, and the effect of map location in the vehicle.

Nowakowski, C. and Green, P. (1998). Map Design: An On-the-Road Evaluation of the Time to Read Electronic Navigation Displays (Technical Report UMTRI-98-4).

> This report summarizes an on-the-road study that was run in parallel with the previous report and examined similar factors. The same text sizes and number of streets were used, but all the streets were labeled and the effect of day and night was studied. These results were used to bridge the laboratory results to real, on-the-road situations.

Brooks, A., Nowakowski, C., and Green, P. (1999). Turn-by-Turn Displays versus Electronic Maps: An On-the-Road Comparison of Driver Glance Behavior (Technical Report UMTRI-98-37).

> This report describes an on-the-road study that examined when and how often drivers look at turn-by-turn and electronic map displays in route guidance. Factors examined included road type (residential, freeway, etc.) and the distance to the next turn/decision point.

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INTRODUCTION

Overview

Automotive navigation systems are commonplace in Japan and are becoming more popular in Europe, the United States, and other parts of the world. These systems allow drivers to enter destinations through a variety of methods and provide turn-by-turn, map-based, and voice guidance to those destinations.

Numerous safety and usability studies of navigation systems have been conducted to assure that such systems do not present undue risk to drivers (Dingus, Antin, Hulse, and Wierwille, 1989; Labiale, 1989; Dingus, Hulse, Krage, Szczublewski, and Berry, 1991; Green, 1992; Dingus, McGehee, Hulse, Jahns, Manakkal, Mollenhauer, and Fleischman, 1995; Green, Hoekstra, and Williams, 1993; Green, Williams, Hoekstra, George, and Wen, 1993; Schraagen, 1993; Ito and Miki, 1997; Katz, Fleming, Green, Hunter, and Damouth, 1997; Kimura, Marunaka, and Sugiura, 1997; Manes, Green, and Hunter, 1998). These studies have addressed issues such as the usability of various navigation methods (paper maps, instructions lists, voice guidance, point-on-a-map displays, turn-by-turn displays, etc.) and combinations of them, as well as the usability of various data entry methods (scrolling lists, alphabetic entry, etc.).

Initial cost is a very important influence on decisions to purchase navigation systems. One way to hold costs down is to use a single, small display. If that is the case, then display options are (1) always show a map, (2) always show a turn-by-turn display, (3) allow the driver to switch (by pressing a button) between a map and a turn-by-turn display, and (4) have the navigation system "know" at each moment which display the driver wants and automatically present it. There have been no studies exploring this ideal fourth choice in the literature, so this preference experiment was conducted.

There are, however, several studies in the literature that concern related topics. The use of route maps and turn-by-turn displays was examined thoroughly in the TravTek camera car study (Dingus, McGehee, Hulse, Jahns, Manakkal, Mollenhauer, and Fleischman, 1995). In the study, subjects used a TravTek vehicle to drive to destinations using six navigation methods: a paper map, a paper direction list, and four TravTek configurations (turn-by-turn and route map, both with and without voice). Subjects used only one navigation method per destination. All glances within the vehicle were recorded and the percentage of glances to each area was examined for the different navigation methods. Comparing the conditions of turn-by-turn and route map displays with voice navigation, the percentage of glances to the turn-by-turn display was slightly lower than for the route map display (16 and 18 percent of all glances, respectively). Also, the total number of display glances was slightly lower for the turn-by-turn display. Therefore, the turn-by-turn display required less in-vehicle attention than the route map display. Compared to the navigation conditions with voice, the conditions without voice nearly doubled the number of display glances and also greatly increased the percentage of glances, therefore requiring higher visual attention. Overall, the turn-by-turn with voice was a better interface for performance than the route map with voice.

More recently, Srinivasan and Jovanis (1997) examined reaction times to a scanning task when navigating with route guidance systems in the Hughes driving simulator. The scanning task was to monitor squares on each roadway boundary (one on each side) for changes in shape; the squares rotated 45 degrees to become diamonds. Once drivers detected the change, they pressed a button on the left or right side of the steering wheel corresponding to the square that rotated. This task was performed while the subject followed the navigation system to arrive at a destination. In addition to the response times to the scanning task, data were collected on navigation errors and also subjective workload using the NASA Task Loading Index (TLX). An original hypothesis was that the turn-by-turn display was simpler than the route map display and would therefore require less attention and hence lead to lower reaction times. However, the results of the study showed that the reaction times when using the route map display were about 11 percent lower than when using the turn-by-turn display. This result suggests that the route map display required less visual attention than the turn-by-turn display. Also, the route map contained information that was not available from the turn-by-turn display. According to the study, participants liked knowing the number of blocks to a decision point, information that was only available from the route map display.

Another topic of consideration was that of map scale (or zoom level). Dingus, Antin, Hulse, and Wierwille (1989) performed an on-the-road study that examined task completion times when interacting with an Etak Navigator. Task completion times were highest (road attention was lowest) when subjects had to manually change zoom levels. Therefore, an ideal design feature for maps would be to automatically change scale to provide more detail as the driver approaches a turn. These findings were used to develop rules for the map zoom levels used in the current experiment.

Based on these and other studies, navigation display design guidelines have been developed (e.g., Green, Levison, Paelke, and Serafin, 1995). Both the route map and turn-by-turn displays used in this experiment followed these general recommendations extremely well, with some small exceptions. One guideline suggests that the turn-by-turn display should show two maneuvers in a row when turns are in close proximity (less than about 0.1 miles apart). There were points along the experimental route where turns were closely spaced, and this guideline was not followed. Another guideline says that the road information given should agree with the road signs drivers are likely to see. In some cases, the turn-by-turn information provided did not match perfectly with the actual road sign (e.g., Church Rd. and Church St.), thus departing from the guideline. These departures were relatively minor and the overall design of the navigation displays was very good.

In addition to research, practical experience provides some insight into the need for navigation systems and the desired format for visual displays. Preference for turn-by-turn versus route map displays depends upon regional geography. In the United States, where many cities were planned developments from their inception, city streets are typically in a grid pattern (such as in Manhattan, Philadelphia, or Detroit) with logical street name progressions. (First Street is followed by Second Street, 8-Mile Road is one mile south of 9-Mile Road, etc.) For some statistical evidence on this issue for the United States, see Brooks, Lenneman, George-Maletta, Hunter, and Green (1999), the initial experiment in this project. In Europe, city streets are more often found in a pinwheel shape that extend radially outward, reflecting their evolution over a longer period of time from a central core. This makes road navigation more difficult than in the United States. In Japan, street networks are rarely gridlike, many streets do not have names, and buildings are numbered chronologically. (So, 100 Matsui Street could be many miles from 101 Matsui Street.) Also, the street name progressions found in the United States do not typically exist in either Europe or Japan. Thus, road navigation in Japan is even more difficult than in Europe, and these levels of difficulty are being reflected in the sales of navigation systems.

One consequence of these regional differences is that display format preferences vary. Route maps facilitate easier navigation when street patterns are irregular, while turn-by-turn displays can make navigation easier when street patterns are very regular and consistent. Therefore, route maps would be the display of choice in Japan (and sometimes in Europe) while turn-by-turn displays would be the primary choice in the United States. However, the particular display appropriate at any given moment will depend upon many factors: the extent to which the driver needs turn versus orientation information at that moment, whether the driver is planning or following a route, the personal preference of the driver, and possibly the complexity of the maneuver.

Issues

To develop an automatic display switching algorithm, three issues were examined.

1. Which display is glanced at more during route guidance, a turn-by-turn display or a route map display?

The greater the glance frequency, the more important it is for the display to be shown. Therefore, the number of glances to the turn-by-turn and route map displays were examined. Furthermore, the effects of display location were examined, as each display was located on either the right side or left side of the steering wheel.

2. What driver and road-related factors affect display glances?

Driver differences such as age and gender could affect the use of navigation displays, and therefore were equally balanced and included in the evaluation. One might suspect that older drivers would have more difficulty navigating and might look at in-vehicle displays more often. The influence of road type and segment length were also considered, with three road types examined (freeways, city streets, and residential streets) of varying segment length.

3. When do display glances occur along road segments?

One of the most important issues addressed in this experiment was finding when drivers glance to a certain display along a road segment. Within a particular segment, the glance rates can be compared at different distances from the turn, yielding histograms of glance behavior. This information will also help to select the best display for any given moment.

TEST PLAN

Overview

During the experiment, subjects drove a car on roads in the Ann Arbor, Michigan, area. Subjects drove on freeways, rural roads, and city streets. The test vehicle was equipped with two identical route guidance displays, one on each side of the steering wheel. The two systems guided the subject to the same destination. One displayed a route map while the other displayed a turn-by-turn indicator. Subjects followed the route guidance systems to specified destinations.

Test Participants

Sixteen licensed drivers participated in the experiment, 8 young (20 to 29 years, mean = 25) and 8 older (66 to 73 years, mean = 69). As shown in Table 1, subjects were divided equally by age, gender, and display location. All subjects were respondents to a newspaper advertisement. The study took approximately 2 hours and subjects were paid $30 for their participation.

Table 1. Subjects.

Display Locations		Young		Older	
Turn-by-Turn	Route Map	Male	Female	Male	Female
Right	Left	2	2	2	2
Left	Right	2	2	2	2

Corrected visual acuity for young subjects ranged from 20/15 to 20/40 (mean = 20/22) and from 20/17 to 20/40 (mean = 20/25) for the older subjects. Corrective eyewear (glasses or contacts) were worn by 11 (5 young subjects and 6 older subjects) of the 16 subjects.

Subjects drove approximately 10,500 miles per year with men driving an average of about 2,500 more miles than women. Prior to the study, none of the subjects had driven a vehicle with an in-vehicle navigation system. Subjects reported using a map an average of 5 to 6 times in the past six months. Most young subjects reported the frequent use of a computer, while older subjects either used a computer daily or never (three used one daily, and five never used one).

Subjects also reported their familiarity with Ann Arbor roads on a scale of 1 to 5, with 1 being "not at all familiar" and 5 being "very familiar." The average response was 3.7, with older subjects being slightly more familiar with the area than young subjects. Responses ranged from 2 to 5, with the most common response being 4.

Test Vehicle

The test vehicle, the UMTRI Driver Interface Research Vehicle, was a highly instrumented, left-hand drive 1991 Honda Accord station wagon with an automatic transmission, power steering, and power brakes. The vehicle was equipped with two Magellan PathMaster navigation units utilizing a global positioning system (GPS), as well as a number of cameras for recording different types of information, such as the forward scene and the driver.

The PathMaster display units, 13.5 cm wide by 15.5 cm tall, showed either a route map or a turn-by-turn display. The actual display screen was 8 cm wide by 6.4 cm tall, with a 10 cm diagonal. An example of the turn-by-turn display is shown in Figure 1. Information given by the turn-by-turn display included the next road on which to turn, the direction of that turn, the distance to that turn, and a countdown bar indicating when that turn was to occur.

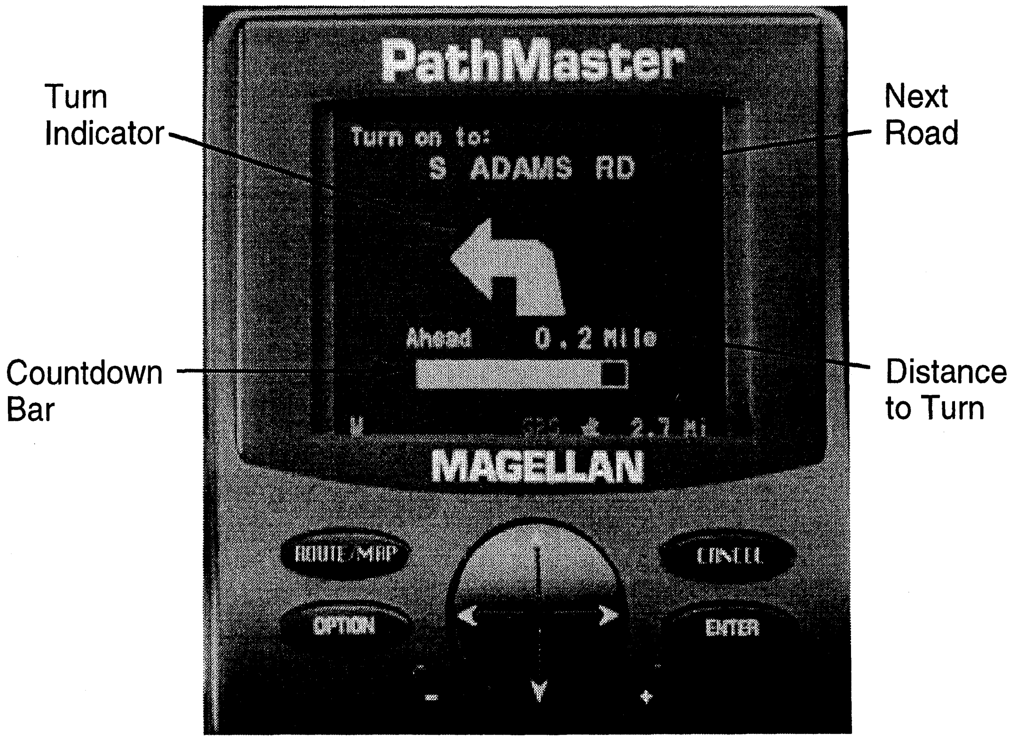


Figure 1. PathMaster turn-by-turn display.

The two PathMaster navigation display units were mounted one on each side of the steering wheel, as equidistant from the steering wheel as permitted by the interior. The unit on the left side of the steering wheel was mounted to the left A-pillar while the right unit was mounted to the top of the dashboard. The right unit required an additional support post, between the unit and the floor console, which prevented the display from vibrating. Using a 6'0" male driver, the display viewing angles and distances were also measured and are summarized in Table 2. The complete dashboard layout is shown in Figure 2.

Table 2. Display viewing angles and distances.

	Degrees			Viewing
Display	From Center	Below Horiz.	Inward Tilt	Distance (cm)
Left	20 (left)	15	20	66.7
Right	26 (right)	15	20	71.1

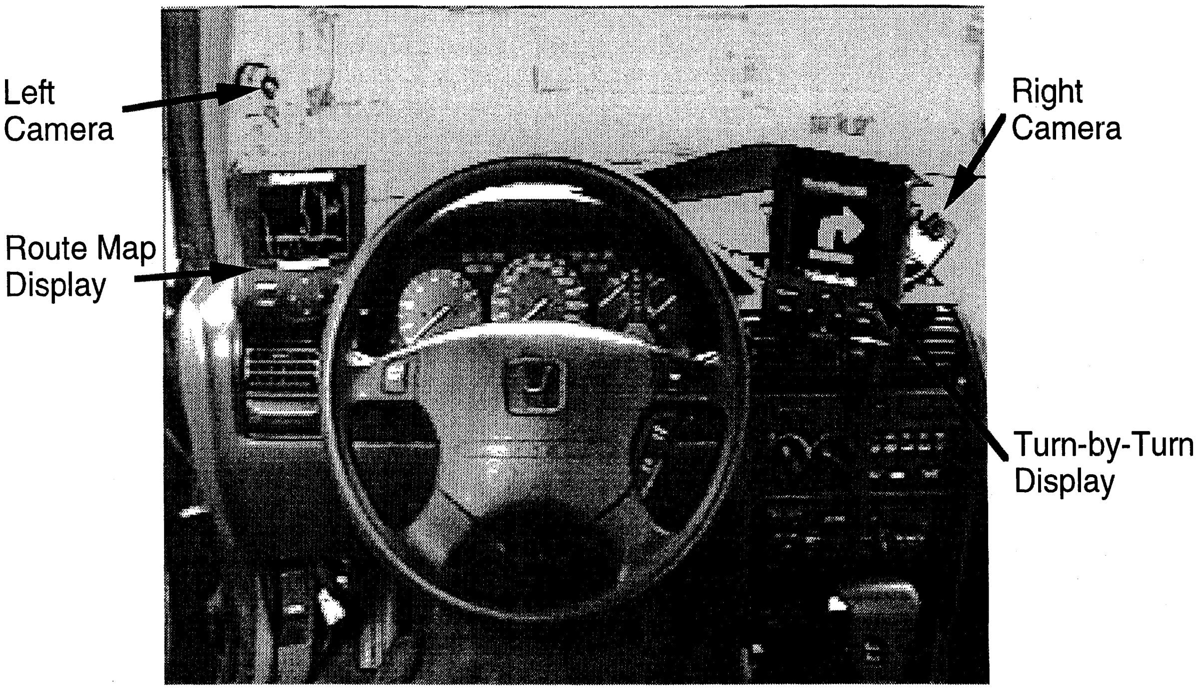
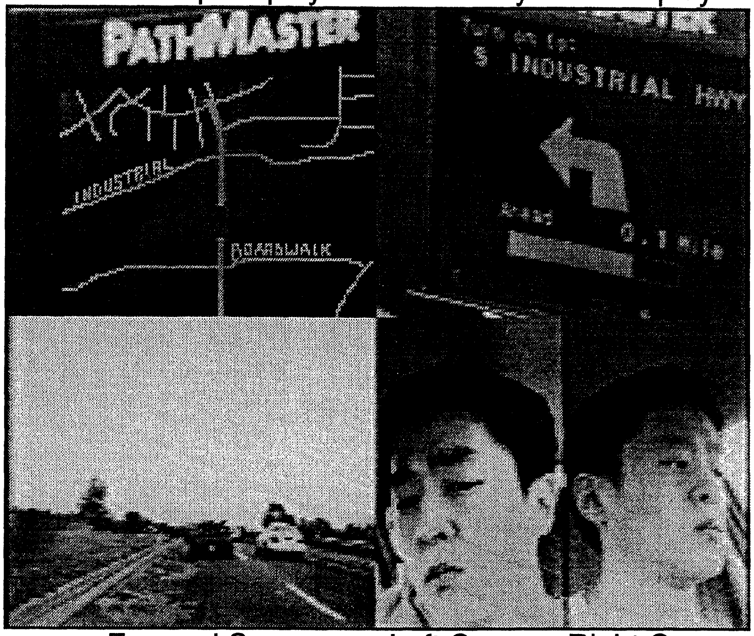


Figure 2. Drivers' dashboard view. Note: the location of the turn-by-turn and route map displays was counterbalanced between subjects.

The two navigation computers for the PathMaster display units, located in the back of the vehicle, ran Version 3.32 of the GPS software and used the Great Lakes area database, version 30J.0372.01.

The video recording system consisted of three bullet (lipstick) cameras, and two low-light cameras. Two of the lipstick cameras were aimed at the driver, one near each display position (shown in Figure 2), and were used to determine when drivers looked at each display. A third lipstick camera recorded the forward scene and was mounted below the inside rearview mirror. The two low-light cameras, which recorded the left and right displays, were mounted behind the driver, one over each shoulder. Camera outputs were combined by a quad splitter, displayed on a monitor, and recorded on a VCR. The two driver images were combined by a two-image splitter and filled one quadrant of the quad splitter image. (See Figure 3.) For the data analysis, the distance to the turn and the time were noted for each glance to a display. Therefore, not only could glance behavior be shown as a function of the distance to the turn, but also the time to the turn.

Route Map Display Turn-by-Turn Display



Forward Scene Left Camera Right Camera

Figure 3. Typical quad-split image.

The video equipment could either be powered by the car, or when stationary, by a 110-volt AC wall outlet source. During on-road tests, a 400-watt, 110-volt AC power converter provided supplemental power. No supplemental batteries were used to power the equipment.

Sound was picked up by two miniature lavolier microphones, one mounted on the left A-pillar, a second mounted on the inside rearview mirror. An audio mixer combined the two microphone outputs for recording on one of the VCR's audio channels.

All equipment was operated by an experimenter seated in the right rear passenger seat. Using the video display showing the quad-split output (Figure 3), the experimenter monitored the camera output, making adjustments as necessary. An equipment rack, shown in Figure 4, was located next to the experimenter (and behind the driver) and contained all the camera controls, a VCR, an audio mixer, and a video display. The two low-light cameras used to view the PathMaster displays were mounted above the equipment rack. Also in the back seat was a custom-made remote access controller that duplicated all of the navigation unit switches (shown in Figure 1). Appendix A shows a plan view of the test vehicle and the model numbers of all equipment in the vehicle.

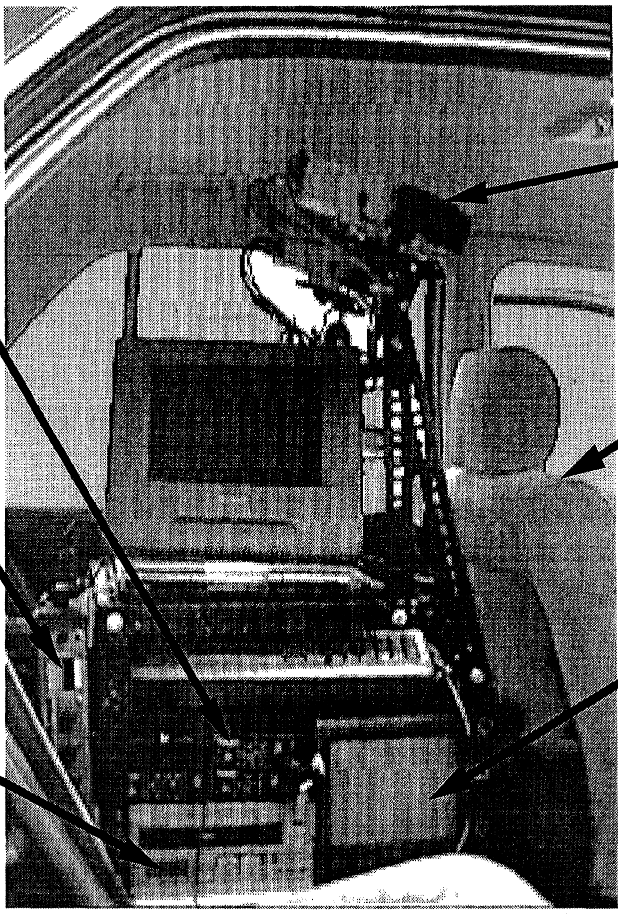


Figure 4. Experimenter equipment.

Test Activities and Their Sequence

Each subject began by completing a participant consent form (Appendix B) and a biographical form (Appendix C) followed by a vision test. See Appendix D for the complete instructions given to each subject by the experimenter.

At the test vehicle, subjects were given all necessary instructions concerning the use of the guidance systems and the experimental protocol. The experimenter then started the videotape. The experimenter told the subject to put the vehicle in drive and follow his guidance. To calibrate the navigation system, the experimenter guided the subject through the first few turns. Subsequently, the experimenter retrieved the first practice destination while the subject was driving using the custom made remote access controller. When a destination was reached, the subject parked the vehicle while the experimenter retrieved the next destination.

Since the preference for a route map versus a turn-by-turn display would depend on the map scale selected at any time, the experimenter periodically changed the zoom level to what was believed to be optimal based on pilot data. Three discrete zoom levels were used: 1/4-, 1-, and 4-mile scales (number of miles per inch on screen). The 1/4-mile scale was heading-up (current direction at the top of the screen) and the 1- and 4-mile scales were north-up (north at the top of the screen). The PathMaster units had 1/8- and 16-mile scales which were not used; the 1/8-mile scale was too close and updated too often while the 16-mile scale was unable to show enough detail. Using the results of Dingus, Antin, Hulse, and Wierwille (1989), two general rules were generated that dictated the chosen zoom levels for each road section: 1) the next turn should be shown on the route map with the lowest zoom level possible, and 2) do not use a north-up orientation when heading south (not applicable on freeways). Using these two rules, the zoom levels applied at certain distances from the next turn were generated and are summarized in Table 3. On city roads, the 1/4-mile scale was always set when the vehicle was 0.3 miles from the next turn. Furthermore, if the vehicle was traveling south, the map scale remained at 1/4-mile, regardless of the distance to the next turn. This was done to avoid the confusion created when the vehicle icon completely switches direction between the north-up and heading-up orientations. The 4-mile scale was used only on the freeway. A summary of the zoom levels used along the route is located in Appendix E.

Table 3. Zoom levels.

		Miles to Next Turn		
Road Type	Heading	0 - 0.3	0.4 - 1.5	1.5 - 6
City	North / East / West	1/4	1	1
	South	1/4	1/4	1/4
Freeway	Any	1/4 or 1*	1	4

* 1/4 on merge and exit ramps; 1 until vehicle had exited.

The PathMaster navigation units also had built-in audio capabilities. The list of voice instructions encountered in the experiment are summarized in Table 4. When the vehicle was about 0.2 miles from a turn, the unit beeped twice, spoke one of the instructions, and then beeped once about 250 feet from the turn. During the experiment, the voice was set to the highest volume level on the turn-by-turn display and was turned off on the route map display to avoid duplicate voice instructions. The voice was chosen to be active on the turn-by-turn display because it was best coordinated with the specific maneuvers. The short beeps could not be deactivated, so both units beeped during the experiment, which did not confuse subjects.

Table 4. System voice instructions.

Road Type	Turn Type	System Says:
City	Left Turn	"Left Turn Ahead"
	Right Turn	"Right Turn Ahead"
	Straight	"Stay Straight on the Current Road"
	Merge	"Merge Ahead"
Freeway	Exit near (about 1 mile)	"Prepare to Exit"
	Left Exit	"Next Exit on the Left"
	Right Exit	"Next Exit on the Right"
	Straight	"Stay Straight on the Current Road"
	Freeway Entrance	"Freeway Entrance Ahead, on the Right"
	Right Exit, then Left Turn	"Next Exit on the Right, followed by Left Turn"

Upon completion of the test route, each subject responded to a post experiment evaluation (Appendix F), filled out a payment form, and was paid. The experiment took approximately 2 hours to complete.

Test Route

The experiment was conducted on roads in the Ann Arbor area with subjects driving on freeways, rural roads, one-way and two-way city roads, and residential roads. The test route, which started and finished at UMTRI, consisted of two practice destinations and six experimental destinations which covered a total of approximately 37 miles. Appendix G shows the overall test route as well as the individual destinations.

The two practice destinations served (1) to highlight certain features of the navigation systems, (2) to get the subject comfortable with using the navigation units, and (3) to get the subject used to driving the test vehicle. Specifically, the first practice destination demonstrated the use of the countdown bar on the turn-by-turn display. The second practice destination showed how the route map could be utilized for closely spaced turns. The practice route took a total of approximately 20 minutes to drive.

Along the route, three types of turns were made: left, right, and continuations. Left and right turns were generally defined as 90 degree turns from one street to another. Continuations were merges onto the freeway or remaining on the current road when it split (such as a freeway split). An attempt was made to equally balance left and right turns along the route. The distribution of turns made along the test route are summarized in Table 5.

Table 5. Distribution of turns by destination.

		Turn		
	Destination	Left	Right	Continuation
Practice	P1	3	1	0
	P2	1	3	0
	Total	**4**	**4**	**0**
Test	T1	4	6	2
	T2	2	2	0
	T3	3	4	3
	T4	1	1	0
	T5	3	2	1
	T6	1	2	0
	Total	**14**	**17**	**6**

It was hypothesized that the desired display (turn-by-turn or route map) and the map scale for a route map display might depend on the distance to the next turn. For example, if one was going to make a right turn in 20 miles, a turn-by-turn display might not be used. Accordingly, the route was constructed so the distances prior to turns varied. Larger segment distances (over 6 miles) were not explored to keep session duration within reason.

Many different types of roads were utilized along the test route and are summarized in Table 6. All freeways along the test route (M-14, US-23, and I-94) had two lanes in each direction and were divided by either a median or barrier wall. The two-lane divided roads were two lanes in each direction, separated by a median. All two-lane roads (city and rural) had a total of two lanes, one in each direction, and were not divided. The four-lane roads had two undivided lanes in each direction, and the four-lane roads with turn had an additional center lane for turning. One-way roads had two lanes, with additional lanes for turning. Roads along the test route were in relatively good condition. The road condition did not greatly affect the behavior of the subjects, as the poor road sections were generally short and did not present any danger.

Table 6. Road types on test route.

	Destination	Length (mi)	Road Types
Practice	P1	3.0	Two-lane divided, two-lane (rural), residential
	P2	3.3	Two-lane divided, two-lane (rural), four-lane, residential
	Total	**6.3**	
Testing	T1	9.8	Freeway, four-lane, two-lane, residential
	T2	4.8	Two-lane (rural), residential
	T3	9.7	Freeway, two-lane (rural), two-lane divided, two-lane, residential
	T4	1.7	Two-lane, four-lane with turn
	T5	2.0	Four-lane, one-way (2 lanes), two-lane, four-lane with turn, residential
	T6	2.7	Two-lane, four-lane, two-lane divided
	Total	**30.7**	

Some minor construction was encountered during experimentation. The construction was along a 1-mile stretch of Washtenaw Road and consisted of closing one of the two lanes in each direction. The behavior of the subject was not altered (as observed by the experimenter), as a normal speed could be maintained and a detour was not required. Construction never occurred at any other points along the route.

Experimentation took place on weekdays at one of four session times: 9:00 - 11:00 a.m., 11:30 a.m.- 1:30 p.m., 2:00 - 4:00 p.m., or 6:30 - 8:30 p.m. on dates between May 26 and June 10, 1998. In general, the three daytime sessions had similar traffic conditions while the evening session had lighter traffic. Friday evenings and weekends were not used for testing because traffic was heavier than during the week. All testing was started well after sunrise and completed before sunset. Testing took place only in good weather (no rain or fog) on dry roads, and sessions canceled due to bad weather were rescheduled. The entire test route used for experimentation (including practice routes) took a total of approximately 1 hour to drive.

RESULTS

Data Reduction

The only data collected in the experiment were the videotaped images of subjects driving the test route. Data reduction from the videotape was relatively straightforward. When the subject was observed on tape glancing to one of the navigation displays, five pieces of data were recorded: (1) the distance to the turn (from the turn-by-turn display), (2) the time the glance occurred (from the VCR counter), (3) which display was viewed, (4) the display location (left or right), and (5) whether glances were in succession. When the turn was finished, that time was also recorded from the VCR counter. Successive glances, quite distinct on tape, were generally defined as any number of glances to either display, separated by 2 seconds or less. Exceptions were made to include glance separations of 3 seconds or exclude separations of 1 second, depending on the specific situation. Although all glances towards the displays were recorded, only those made while the vehicle was moving were analyzed. It must be noted that in this results section, the turn-by-turn display will be referred to as the "turn display" and the route map display will be referred to as the "map display."

After all of the data was reduced, the data was sampled to check for analyst reliability. (See Table 7.) Two segments were sampled for each subject; one segment was a 1.5-mile stretch of a major city road (speed limit 50 mph), and the other was a 1.6-mile stretch of freeway (speed limit 70 mph). These segments were chosen because they were considered to be representative of the other roads and were of significant length. When the vehicle was moving, about 5.5 percent of the glances (or about 16 per subject) did not match between the two video reviews, a reasonably low value. These differences do not reflect a lack of care on the part of the analyst, as there were some instances where it was unclear where subjects were looking.

Table 7. Reliability of data reduction based on repeated samples.

	Glances	All Data	Vehicle Moving
Sample	Matched	531	500
	Unmatched	41	29
	Total	572	529
	% Unmatched	7.2%	5.5%
Actual	Total	4910	4652
	Unmatched (estimated)	352	255
Estimated Ratios	Per subject	22	16
	Per mile	0.69	0.51
	Per segment	0.58	0.42

Another perspective of reliability involved repeated re-examination of a single "typical" subject. The first destination was reanalyzed three times (for a total of four), separated each time by 3 to 5 days to control for learning as much as possible. Table 8 contains the results of the successive data reductions. Through each successive iteration, the number of discrepancies decreased. However, even after the fourth data reduction, more than 3 percent of the glances did not match the prior analysis. Given these small changes found in repeated reduction and the low benefit-to-cost ratio of further review, the results from the first pass were more than adequate.

Table 8. Reliability of data reduction over successive iterations.

		Successive Reduction Iterations		
	Glances	1 to 2	2 to 3	3 to 4
Vehicle Moving	Matched	122	124	126
	Unmatched	7	5	4
	Total	129	129	130
	% Unmatched	5.4%	3.9%	3.1%
All Data	Matched	132	140	141
	Unmatched	13	5	4
	Total	145	145	145
	% Unmatched	9.0%	3.4%	2.8%

Subject Effects

Age and gender affected the total number of glances to the displays made by each subject during the experiment. (See Figure 5.) Young women and older men had a comparable number of glances (average of 239), as did young men and older women (average of 342). The average number of glances for each subject was 291 with a range of 126 to 454. Over the 30.7-mile route, this averaged to about 9.5 total glances per mile for each subject. In a previous on-the-road study that examined route guidance (Green, Williams, Hoekstra, George, and Wen, 1993), each subject made an average of 11 glances per mile over an 18.3-mile route. The roads were similar in both studies, although the current study used some roads of greater length.

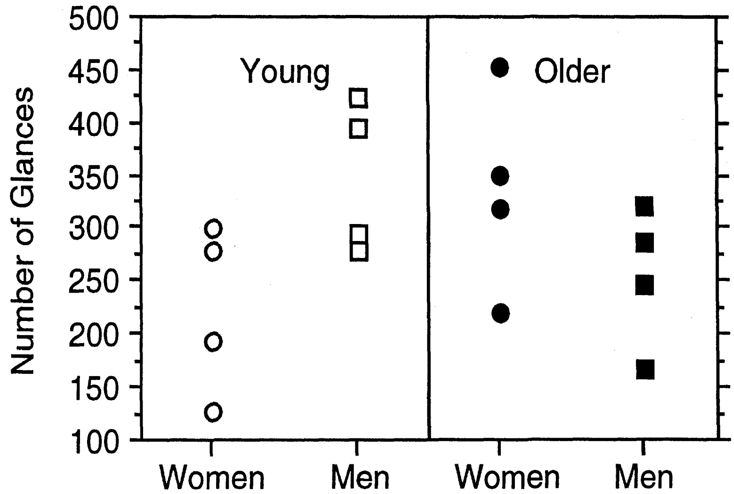


Figure 5. Total number of glances made by each subject.

The display type and the location of the display also affected the number of glances. (See Figure 6.) The turn display was glanced at considerably more than the map display (overall about 3.75 to 1, or 78.9 to 21.1 percent). Therefore, since each subject made approximately 9.5 total glances per mile, about 7.5 would be glances to the turn display and 2 would be glances to the map display. For configuration 1 (turn display on the right, map display on the left), over 85 percent of the glances were made to the turn display (ratio of 5.8 to 1). Conversely, for configuration 2, 72 percent of the glances were made to the turn display (ratio of 2.5 to 1). This indicates both a strong within-subject effect of display type and a between-subject effect of display location.

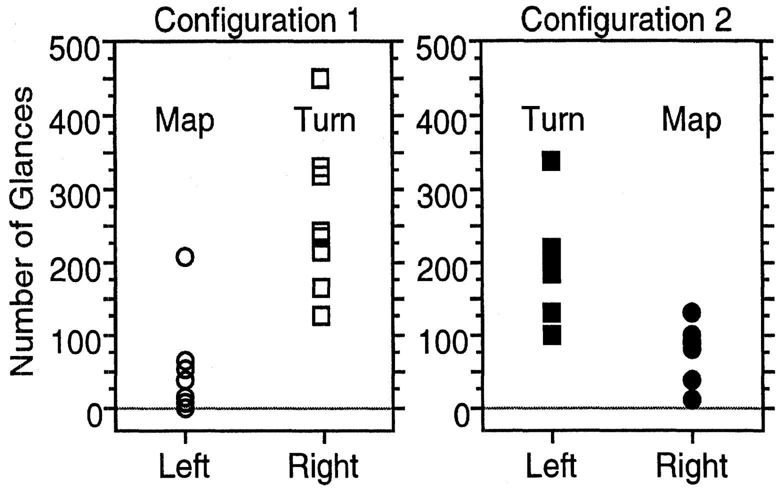


Figure 6. Number of glances by display type and location.

Glance Distributions

The distance to the turn, measured in tenths of a mile, was the primary piece of information utilized in the analysis. Across all subjects, the navigation systems beeped and spoke at the same distance from the next turn. As a result, the distance to the turn was not confounded with any other factors. On the other hand, the time to the turn was dependent upon two confounding factors, vehicle stops (for lights, signs, etc.) and vehicle speed. For this reason, the time to the turn was utilized only when the segment length was very short (0.3 miles or less), where the distance to the turn would not be useful. If stops occurred along a segment in which the time to the turn was utilized, that was noted.

Freeways

The five freeway segments that were driven by each subject were separated into three categories: long, medium, and short distances to the turn. There was one long segment of 5.3 miles, two medium segments of 2.5 and 2.6 miles, and two short segments of 0.6 and 1.6 miles which are typical of urban driving. The total number of glances made to each display and location are summarized in Table 9. Compared to the entire data set, the percentage of turn display glances to map display glances was the same (78.9 to 21.1 percent), but had only an average of 6.9 total glances per mile for each subject (9.5 total glances per mile for each subject over the entire data set).

Table 9. Number of glances by display and location for freeway driving.

	Location		
Display	Left	Right	Total
Turn	488 (34.6%)	624 (44.3%)	1112 (78.9%)
Map	90 (6.4%)	207 (14.7%)	297 (21.1%)
Total	578 (41.0%)	831 (59.0%)	1409 (100%)

The distribution of glances on the long freeway segment is shown in Figure 7. A burst of glances occurred at the beginning of the segment (8.4 glances per mile for each subject over the first 0.2 miles), immediately after the previous turn. This may have been caused by the display changing between segments. Throughout the middle section of the segment, the glance distribution for the turn display was low and relatively uniform (2.9 glances per mile for each subject). The map display was glanced at sporadically throughout the segment, with more glances during the middle portion. The glances to the map display within 1 mile of the turn were induced by the audio cues of the navigation units.

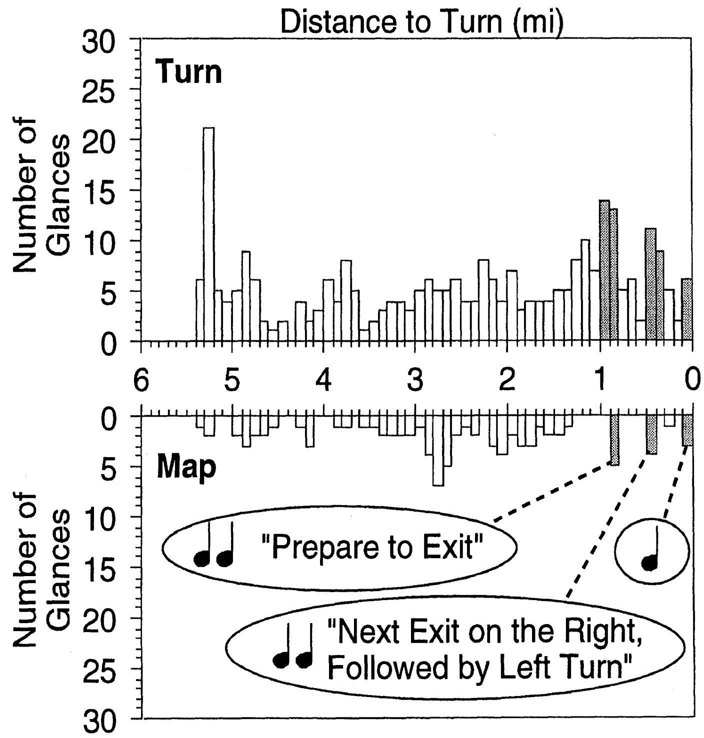


Figure 7. Distance to turn for long (5.3-mile) freeway segment.

The two medium freeway segments resulted in very similar glance distributions. (See Figures 8 and 9.) As with the long freeway segment, numerous glances to the turn display were made immediately following the turns (average of 10.8 glances per mile for each subject), then maintained a relatively constant rate throughout the middle sections (average of 5.1 glances per mile for each subject). Glances to the map display continually increased until peaking near the middle of the segments when glances then began to decrease. Brief increases in the number of glances occurred at the three points where the displays beeped and/or spoke. Interestingly, the two medium freeway segments averaged 7.5 total glances per mile for each subject, compared to about 4.4 for the one long freeway segment. Therefore, subjects glanced to the displays much more frequently when on a shorter freeway segment.

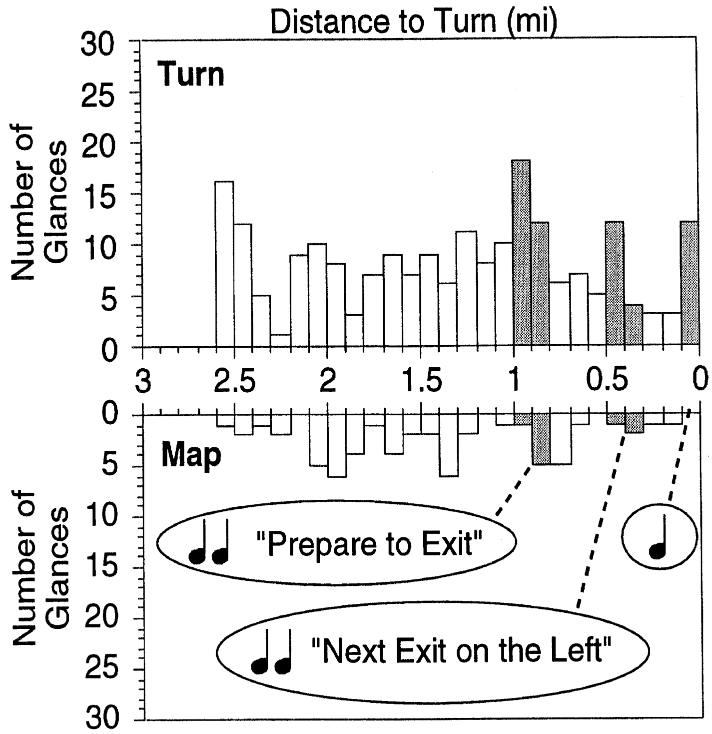


Figure 8. Distance to turn for medium (2.5-mile) freeway segment.

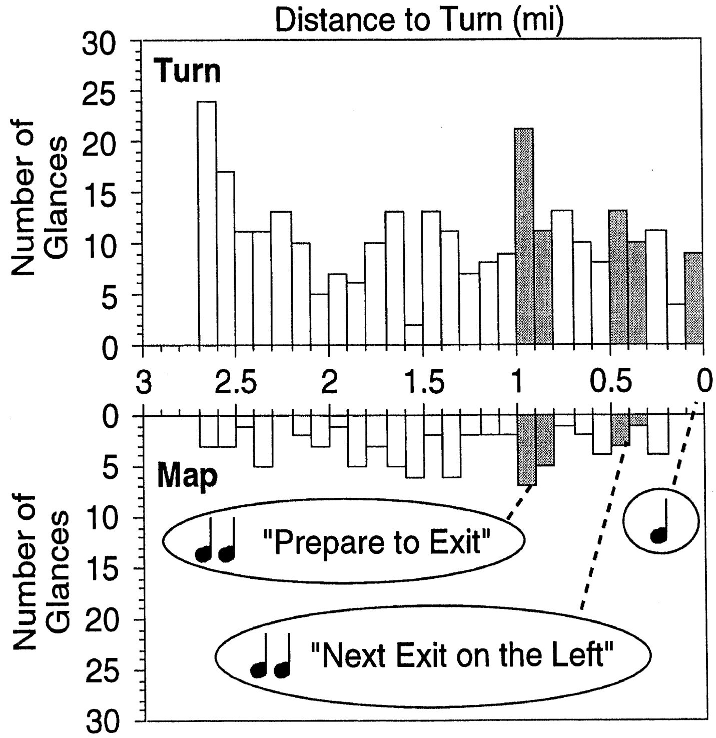


Figure 9. Distance to turn for medium (2.6-mile) freeway segment.

The two short freeway segments yielded similar glance behaviors, displaying a bimodal pattern over the last 0.6 miles. (See Figures 10 and 11.) That is, glances increased over the first portion, peaked and came back down, then increased just before the turn. The turn-display glance distribution for the 1.6-mile segment followed the same general pattern as the long and medium freeway segments. A burst of glances occurred immediately after the turn, then remained uniform for the middle section of the segment. However, since this segment did not contain audio cues at the same points, no burst of glances was observed 0.9 miles from the turn as in previous distributions. Map-display glances were low and uniform throughout the segment.

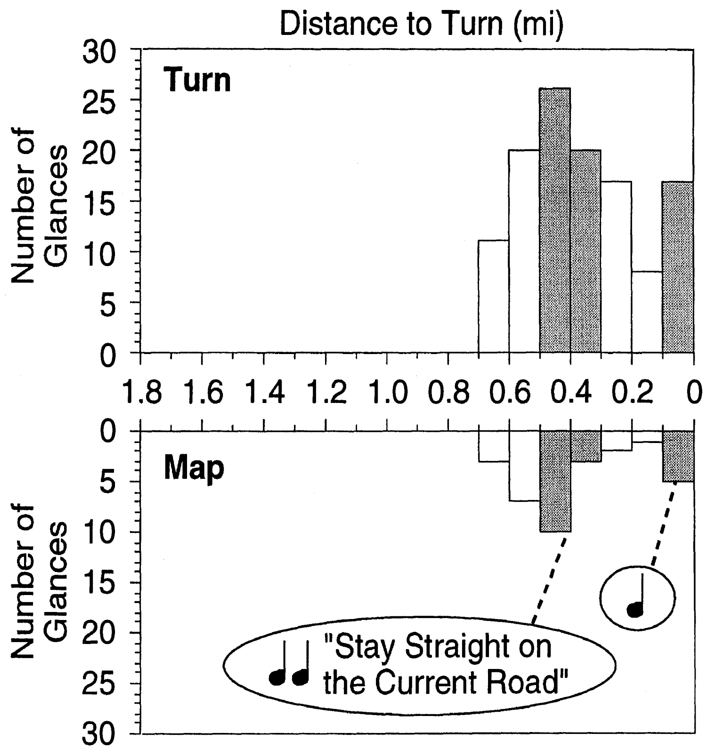


Figure 10. Distance to turn for short (0.6-mile) freeway segment.

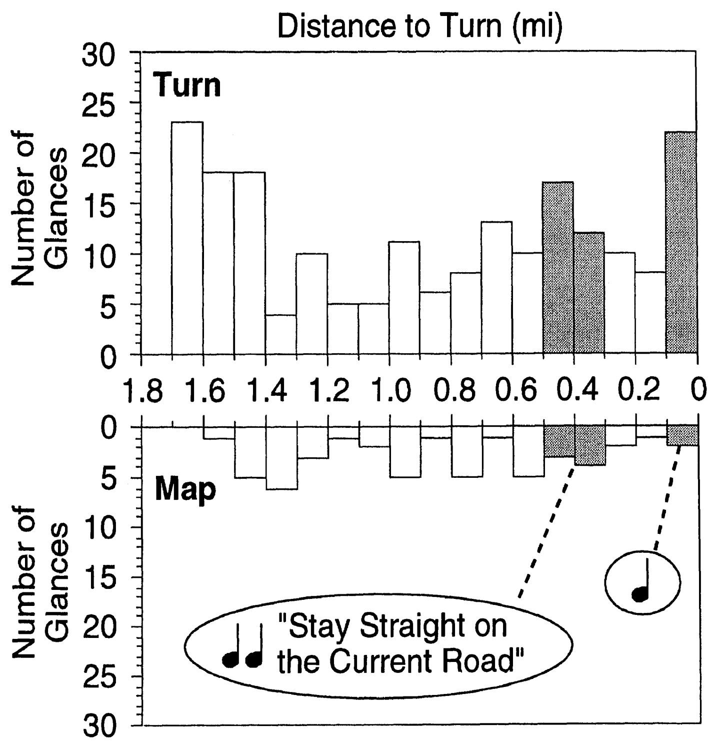


Figure 11. Distance to turn for short (1.6-mile) freeway segment.

Freeway glance distributions are summarized here without the short segments (audio cues were at different points). Map-display glances peaked in the middle of the segments while the general turn-display glance distribution was as follows:

1) Burst at segment start (10 glances per mile per subject over first 0.2 miles)
2) Steady rate over middle sections (4.4 glances per mile per subject)
3) Burst 0.8-0.9 miles from turn (9.3 glances per mile per subject over 0.2 miles)
4) Smaller burst at 0.3-0.4 miles and at turn (6.2 and 5.6 glances per mile per subject)

City Roads

The twenty segments of city roads driven in the experiment were separated into three groups: long, medium, and short distances to the turn. The segment groups, which ranged from 0.0 to 3.9 miles in length, are summarized in Table 10. The total number of glances made to each display and location on city roads are summarized in Table 11. The percentage of turn display glances to map display glances (78.6 to 21.4 percent, or 3.7 to 1) was nearly the same as for the entire data set (78.9 to 21.1 percent) and had an average of 10.8 total glances per mile for each subject.

Table 10. City road segment groups.

Group	Distance (mi)	Number of Segments	Dependent Variable
Long	3.9	1	Distance
	2.1	1	Distance
Medium	1.5	1	Distance
	1.3	1	Distance
	0.9	1	Distance
	0.8	1	Distance
	0.6	2	Distance
	0.5	2	Distance
	0.4	1	Distance
Short	0.3	2	Time
	0.2	2	Time
	0.1	3	Time
	0.0	2	Time

Table 11. Number of glances by display and location for city roads.

	Location		
Display	Left	Right	Total
Turn	886 (33.8%)	1172 (44.8%)	2058 (78.6%)
Map	226 (8.6%)	335 (12.8%)	561 (21.4%)
Total	1112 (42.4%)	1507 (57.6%)	2619 (100%)

The two long city road segments generated very similar glance distributions. A peak of glances to the turn display occurred at the beginning of both the 3.9-mile segment (Figure 12) and the 2.1-mile segment (Figure 13) (average of 12.7 glances per mile for each subject). After the peak, the number of glances to the turn display stabilized for the remainder of both segments (average of 3.9 glances per mile for each subject).

Map-display glance patterns were also similar for both segments, with the beginning of the segments having the highest concentration of glances and then slowly decreasing. About halfway through each segment, glances to the map display began to occur once again and then slowly decreased. For both segments, the number of glances to both the turn and map displays increased slightly when the system spoke near the turn.

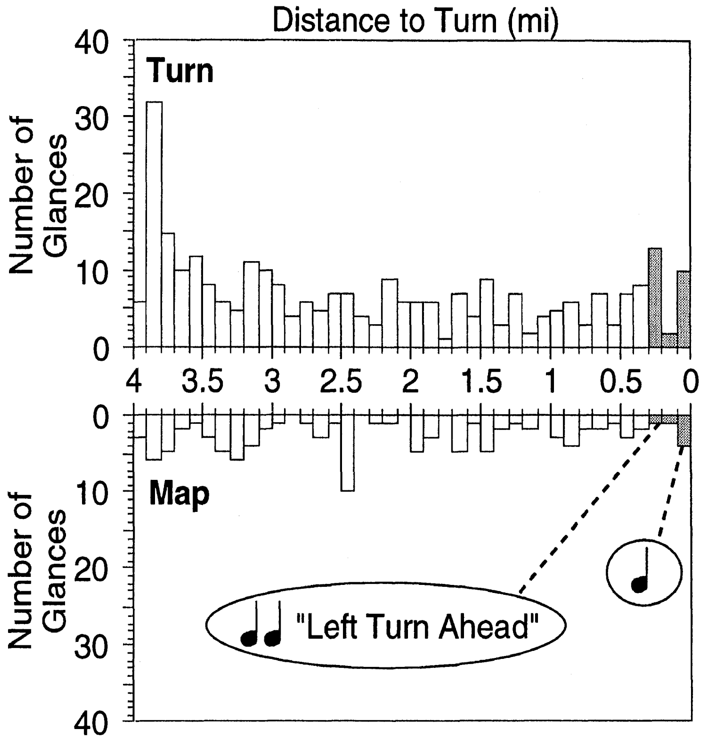


Figure 12. Distance to turn for long (3.9-mile) city road segment.

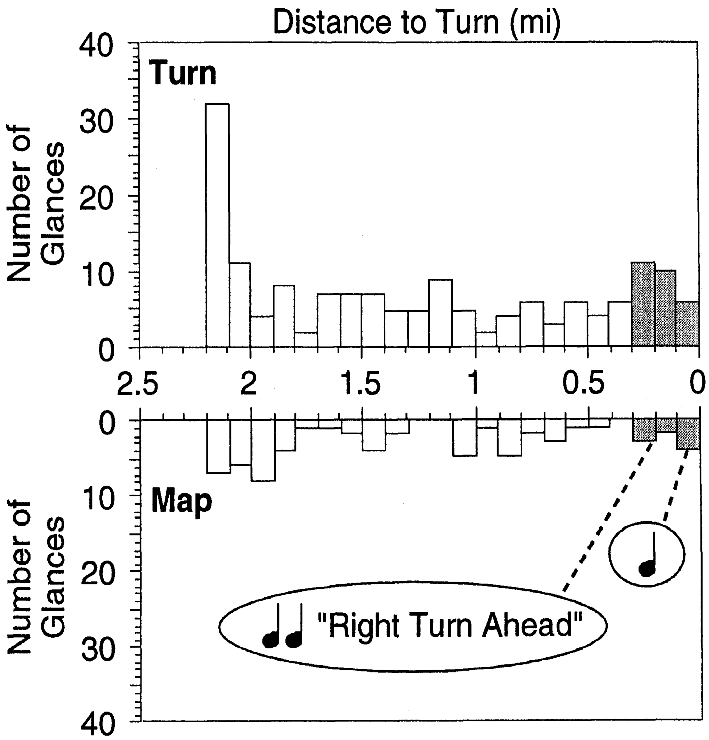


Figure 13. Distance to turn for long (2.1-mile) city road segment.

The nine medium-length city road segments, which were split into seven distance groups, generated differing glance distributions. Two of the groups are analyzed here and the other five are shown in Appendix H. The longest of the medium segments, 1.5 miles (Figure 14), exhibited a glance distribution similar to the two long city road segments of 3.9 and 2.1 miles (Figures 12 and 13). That is, a peak of turn-display glances occurred at the beginning of the segment (17.5 glances per mile for each subject over the first 0.2 miles), then leveled out for the remainder of the segment. An average of 5.5 turn-display glances occurred over the remainder of the segment (0.0 to 1.3 miles from the turn), with a slight increase after the system spoke. The number of map-display glances also peaked at the beginning and followed a decreasing trend over the length of the segment, with one increase at 0.3 miles from the turn.

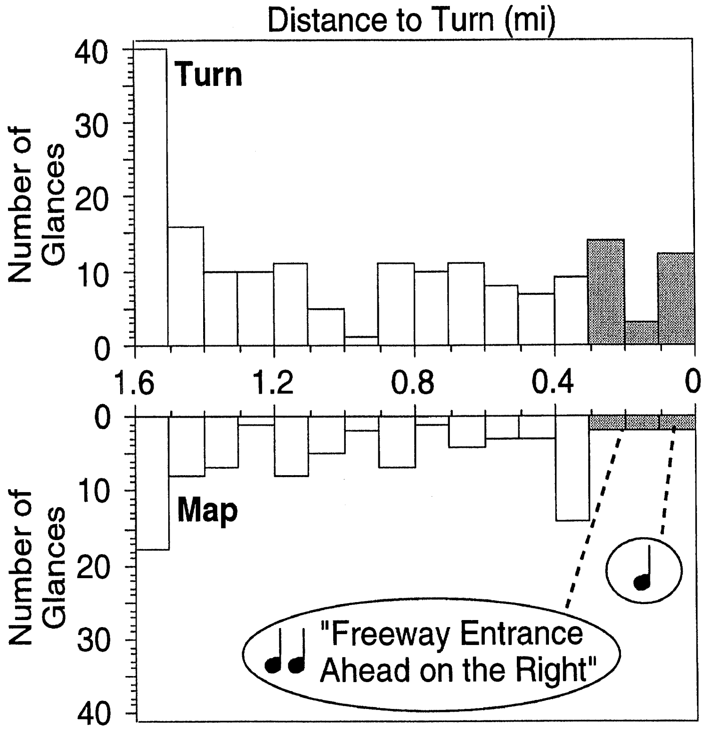


Figure 14. Distance to turn for medium (1.5-mile) city road segment.

The 1.3-mile medium city road segment displayed a relatively uniform distribution for both the turn and map displays. (See Figure 15.) A higher number of turn-display glances occurred at the beginning of the segment (1.3 miles from the turn) and when the system spoke (0.2 miles from the turn). Furthermore, over the middle portion of the segment (0.3 to 1.1 miles), an average of 9.7 turn-display glances occurred per mile for each subject. The map display averaged only 1.3 glances per mile for each subject over the entire segment.

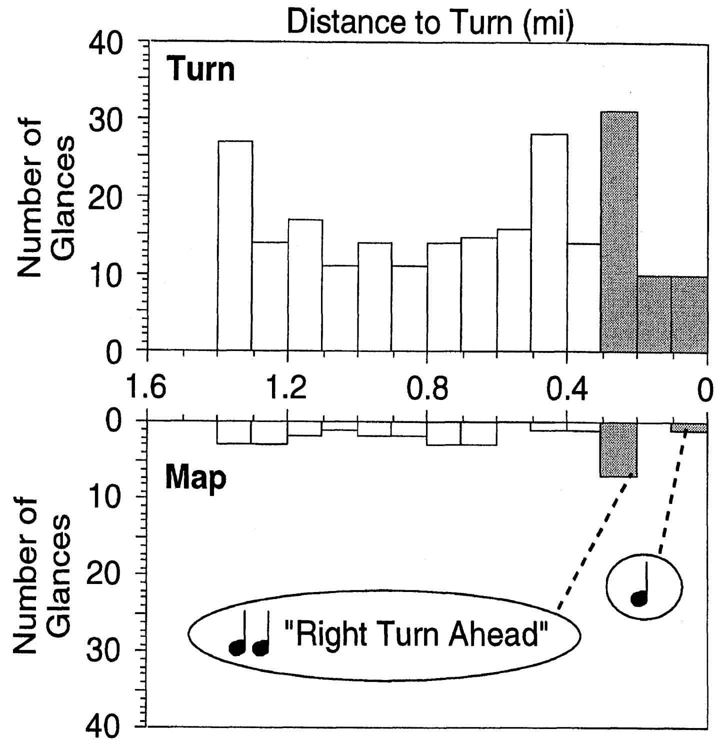


Figure 15. Distance to turn for medium (1.3-mile) city road segment.

City glance distributions (including 0.9-mile and 0.8-mile segments from Appendix H) are summarized thus far. The most map-display glances occurred near the beginning of the segment and the general turn-display glance distribution pattern was as follows:

1) Burst at segment start (14.95 glances per mile per subject over first 0.2 miles)
2) Steady rate over middle sections (6.7 glances per mile per subject)
3) Small burst 0.3 miles from turn (7.0 glances per mile per subject over last 0.3 miles)

Nine short city road segments (0.3 miles or less), which were split into four distance groups, were analyzed using the time to the turn. Two of the groups are analyzed here and the other two are shown in Appendix I. The approximate time to turn for specific events, such as a single beep, are located in Table 12. To calculate these times, an average vehicle speed of 30 mph (44 ft/s or 13.4 m/s) was assumed on these roads.

Table 12. Time to turn for event occurrences.

Segment	Double Beep / Voice			Single Beep		
Group (mi)	Distance (ft)	Time (s)	Range (s)	Distance (ft)	Time (s)	Range (s)
0.3	850	19.3	18-25	250	5.7	4-11
0.2	750	17.0	16-23	250	5.7	4-11
0.1	850	19.3	18-25	250	5.7	4-11
0.0	500	11.3	10-17	150	3.4	2-7

The glance distribution for the two 0.3-mile city road segments is shown in Figure 16. Shortly after the beginning of the segment, many glances to the turn display occurred. However, between 20 and 30 seconds, turn-display glances decreased while map-display glances slightly increased. The ratio of turn-display to map-display glances was 6 to 1, considerably more than the average of 3.75 to 1 for the entire data set.

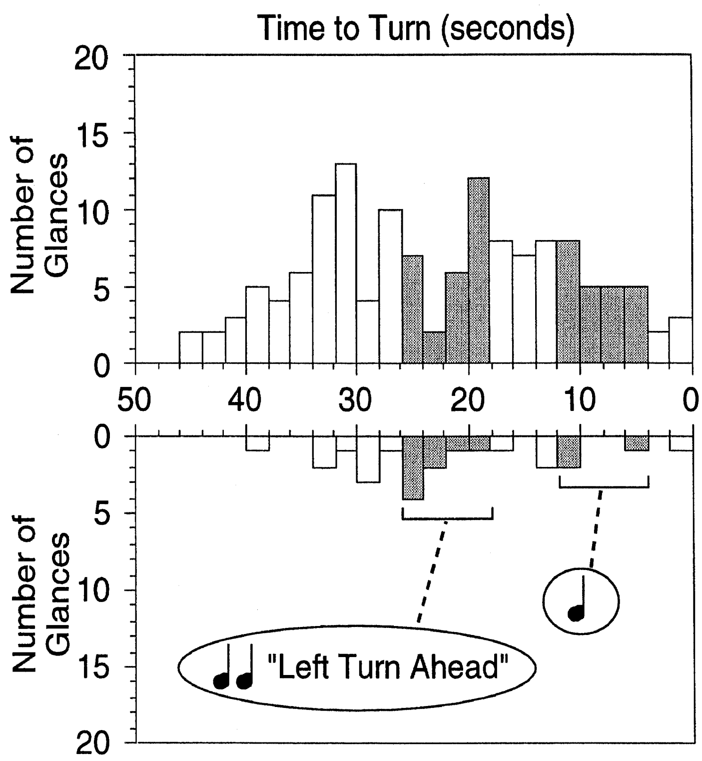


Figure 16. Distance to turn for two short (0.3-mile) city road segments.

The glance distribution for the two 0.2-mile city road segments is shown in Figure 17. Segments of this length and shorter hardly allowed display glances to be made before the system spoke. Therefore, most glances to the displays were induced by the system speaking, whereas the glance frequency may have otherwise been less.

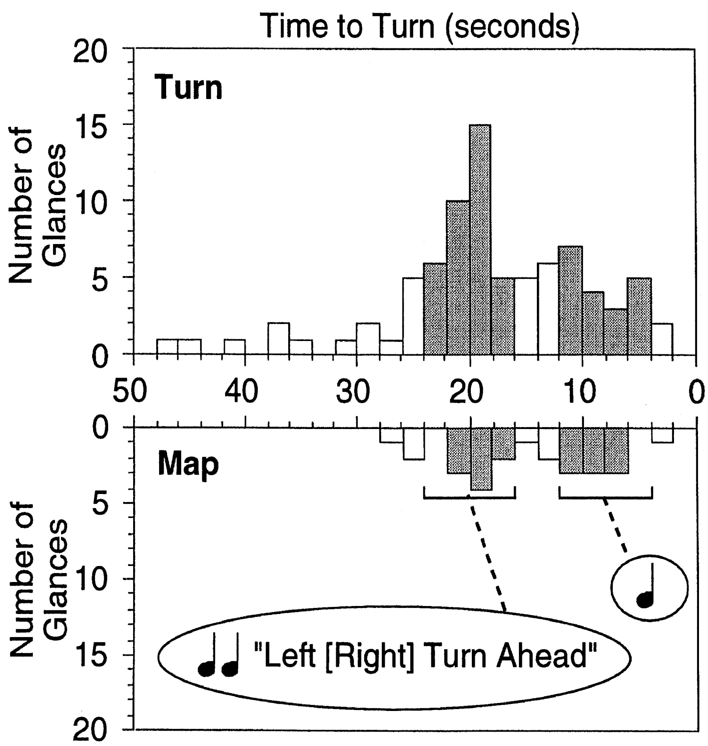


Figure 17. Distance to turn for two short (0.2-mile) city road segments.

Residential Streets

Eight residential streets were driven by the subjects in the experiment. Since the longest residential street was 0.3 miles in length, the time to turn was used instead of the distance to turn. Although the vehicle speed was variable between subjects, no stops were made on any of the residential street segments. Seven of the eight residential segments had a right turn at the end, and one had a left turn. To calculate event times, an average vehicle speed of 20 mph (29.3 ft/s or 8.9 m/s) was assumed. The double beep and voice occurred about 600 feet from the intersection, which translated to 20.5 seconds from the turn with an approximate error range of 18 to 25 seconds. The single beep occurred 250 feet from the intersection, which equated to 8.5 seconds from the turn with a range of 6 to 13 seconds.

The distribution of glances on residential streets as a function of the time to the turn is shown in Figure 18. The ratio of turn-display to map-display glances (4.5 to 1) was much higher than for the freeway or city roads. The frequency of glances increased for both display types as the driver came closer to the turn, reaching a peak around 10 to 12 seconds from the turn. Glances to the turn display began to increase even before the navigation unit spoke (more than 25 seconds from the turn), whereas glances to the map display did not really begin to occur until prompted by the system. The map display was generally not utilized on residential streets, as an average of only 5 glances were made per subject across all 8 segments, compared to 22 turn display glances (over 1.1 miles in approximately 3 minutes).

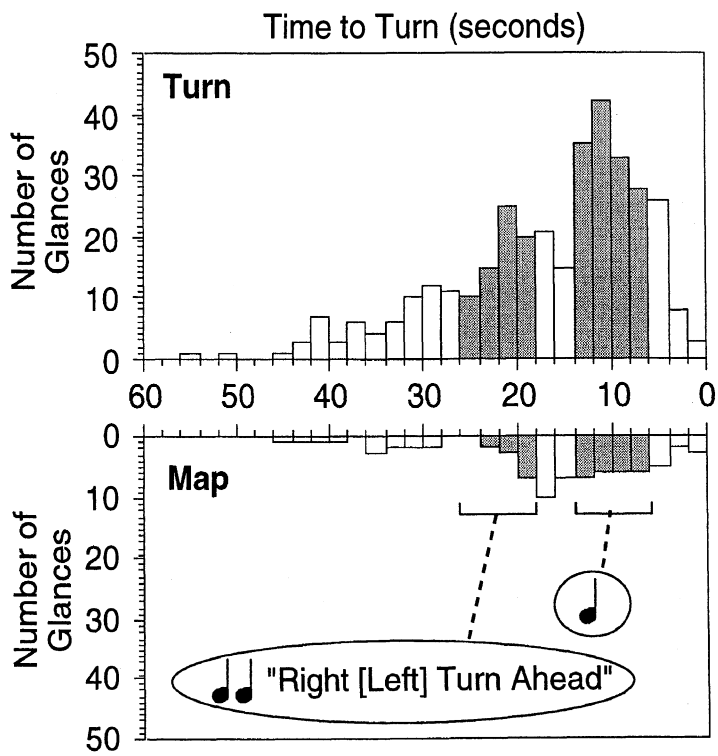


Figure 18. Time to turn on residential streets.

Glance Summary

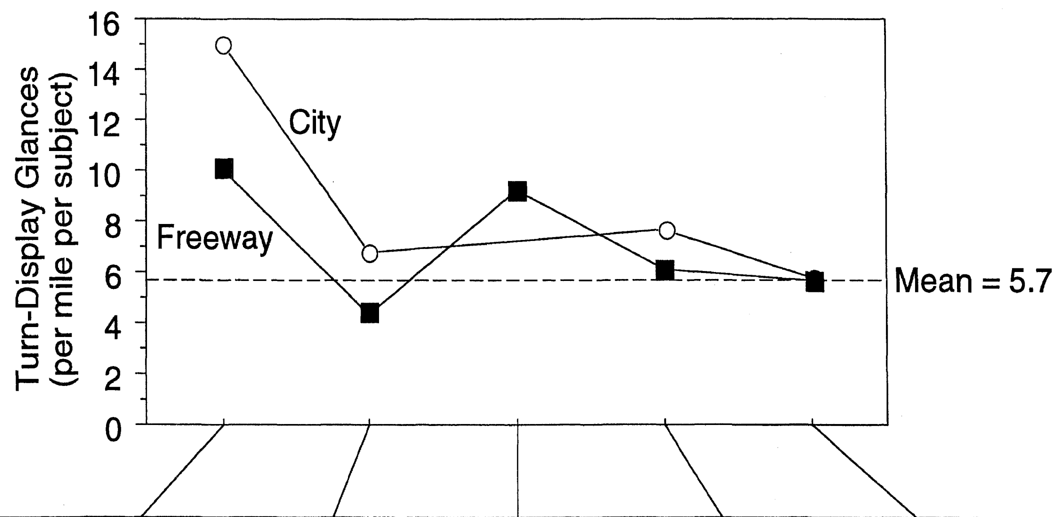
Display glances were summarized using nine freeway and city road segments of long and medium length. The medium-length city road segments used were at least 0.8 miles long.

The overall glance rate was 7.4 total glances per mile for each subject, with 5.7 turn-display glances and 1.7 map-display glances. (See Table 13.) The total glance rate was much higher for city segments than freeway segments, with an average of 2.9 more glances per mile for each subject.

Table 13. Glances and glance rates over freeway and city road segments.

	Display	Freeway (10.6 mi)	City (10.7 mi)	Total (21.3 mi)
Number of Glances	Turn	793	1161	1954
	Map	219	358	577
	Total	1012	1519	2531
Glance Rate (per mile for each subject)	Turn	4.7	6.8	5.7
	Map	1.3	2.1	1.7
	Total	6.0	8.9	7.4

Turn-display glance rates for distinct sections of the freeway and city segments are shown in Figure 19. The most notable point is that turn-display glances are greatest at the beginning of the segment (within 0.2 miles of the previous segment). After the segment start, the turn-display glances remain generally uniform for the remainder of the segment, with slight increases when the navigation system speaks.



Segment Portion	Start	Middle	"Prepare to Exit"	Turn Indication	At Turn
Distance from turn (miles)	Always first 0.2 miles after previous turn	Between "Start" and first speech	0.9 to 0.8	city: 0.2 to 0.1 freeway: 0.4 to 0.3	0.0

Figure 19. Turn display glances for freeway and city segments.

The 29 other segments (8 residential, 2 short freeway, 9 short city, 5 medium city, and 5 freeway ramps) totaling 9.4 miles had an average of 14.1 glances per mile for each subject. The nine summary segments previously discussed (of greater length) had an average of 7.4 glances per mile for each subject. Therefore, the total glance rate generally decreases as the segment length increases across different road types. (See Figure 20.)

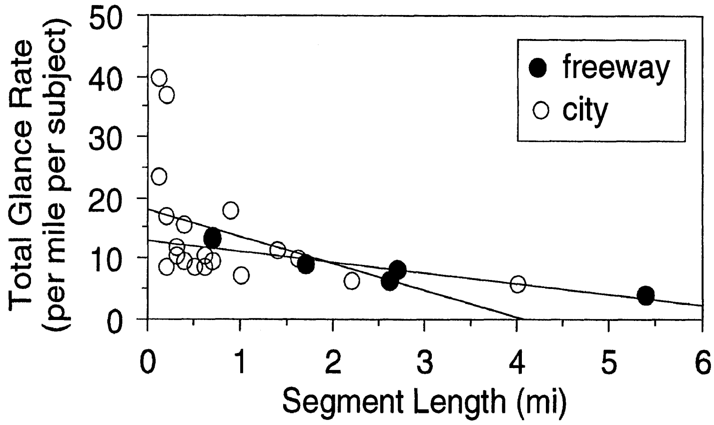


Figure 20. Glance rate by segment length.

Successive Glances

Single glances accounted for 82.2 percent of map-display glances and 76.8 percent of turn-display glances (Table 14). For glances to the map or turn display alone, two or fewer glances were necessary 92.3 percent of the time and three or fewer 97.4 percent of the time. The map display was not glanced at more than 6 times in a row, while the turn display was glanced at up to 12 times in a row. When subjects glanced between the map and turn display, 49 percent (172 out of 350) were a single glance to each display (turn then map or map then turn). Of these 172 occurrences, 93 were "turn then map" (54 percent) and 79 were "map then turn" (46 percent).

Table 14. Occurrences of consecutive glances.

	Glance to:					
	Turn Only		Map Only		Map and	
Glances	Left	Right	Left	Right	Turn	Total
Single	795	969	112	198	-----	2074
2	146	207	14	28	172	566
3	32	88	9	7	98	234
4	9	21	0	6	39	75
5	2	15	1	0	29	47
6	0	6	0	2	3	11
7	0	3	0	0	6	9
8	0	1	0	0	2	3
9	0	2	0	0	0	2
10	0	0	0	0	1	1
11	0	0	0	0	0	0
12	0	1	0	0	0	1
Total	984	1313	136	241	350	3023

Successive glances that included both the map and turn displays (mixed) were analyzed, and the results are summarized in Table 15. For mixed successive glances, 56 percent of first glances (196 out of 350) were to the turn display. Conversely, 52.3 percent of second glances (183 out of 350) were to the map display.

Table 15. Successive glances to both displays.

Glance number	Display: Turn	Display: Map	Total
1	196	154	350
2	167	183	350
3	93	85	178
4	45	35	80
5	15	26	41
6	7	5	12
7	8	1	9
8	3	0	3
9	0	1	1
10	1	0	1
Total	535	490	1025

To analyze subject glance patterns more accurately, a Markov Matrix was applied to the data. The first step was to calculate the probability of initially looking at the turn display or the map display. Then, the probabilities of all four possible combinations of two glances were calculated. (Calculations are located in Appendix J.) The resulting zero-order (M_0) and first-order (M_1) matrices are shown in Table 16.

Table 16. Markov Matrix zero-order (M_0) and first-order (M_1) matrices.

Matrix Order	Previous Glance to:	Next Glance to: Turn	Next Glance to: Map
M_0	(none)	76.9%	23.1%
M_1	Turn	87.2%	12.8%
	Map	35.9%	64.3%

As shown in the zero-order matrix of Table 16, the probability of initially looking to the turn display at the beginning of a glance succession is over 3 times as likely as looking to the map display. The first-order matrix reveals that consecutive glances to the turn display (87.2 percent) or the map display (64.3 percent) were much more likely to occur than glances between the two displays.

Appropriate probability distributions for consecutive glances to the map and turn displays were generated (using up to four consecutive glances) and are shown below. The probability for each consecutive glance to the map display was best represented by a power distribution ($r^2 = 0.998$), while the probability for each consecutive glance to the turn display was best represented by an exponential distribution ($r^2 = 0.995$).

Map: Probability of x successive glances = $81.88 * x^{(-2.797)}$ $r^2 = 0.998$
Turn: Probability of x successive glances = $263.13 * 10^{(-0.578x)}$ $r^2 = 0.995$

Post experiment Evaluation

Subjects were asked a series of six questions upon completion of the experiment. (See Appendix F.) Questions 1 and 2 asked subjects to choose which display they felt was used more often and which they felt was more useful. (See Table 17.) For question 1, most subjects (12 out of 16) felt that they used the turn display more often. In actuality, every subject had more overall glances to the turn display, even those reporting more map usage or equal usage. For question 2, only 9 subjects (out of 16) felt that the turn display had the most useful information, despite the fact that all subjects glanced to this display more often.

Table 17. Number of subjects that chose each display.

Question	Turn	Map	Both Equal
1. Which display did you use most often?	12	1	3
2. Which display had the most useful information?	9	2	5

Questions 3 through 6 concerned how subjects used the displays and their feelings about certain aspects of the displays. The comments that resulted from these questions are summarized in Table 18.

Table 18. Responses to questions 3 through 6.

Question	Comments
3. What information was most critical for guiding you to the destination?	The most common responses were the distance indicator and the arrow graphic on the turn display (half of all responses). Other less common responses included the street name, the countdown bar, and the voice.
4. How did you decide when to look at the map and when to look at the turn display?	"I usually looked at the map right after I made a turn and looked to see where I was going next and about how far. Then I probably didn't look at it anymore for a while until the turn and that's when I started watching this [turn] when I came closer." "If I am far from the turn, I would look at this [map]. If I am pretty close to the turn, I would look at this [turn]." "I looked at this [map] the farther away we were, but I kept looking at this [turn] the closer we came." "I hardly looked at the map; I didn't find it that useful. I just looked at it [map] out of curiosity, not because I thought it was helpful." "I glanced at it [turn] all the time."
5. Was the area shown on the map always set to what you wanted or expected?	"Sometimes I looked down expecting to see the quarter [1/4-mile scale], and I saw the mile one instead. It didn't throw me off, but I think in the city I'd prefer to see the quarter one more often."
6. What did you like or dislike about the system?	"I think you could put it all on one thing. I wonder if they could just make the screen a little bigger and in one corner put [the turn display]." "I think you need smaller gradations on the turn display distance." "I would like to see a larger font size when it says 'take' or 'merge' onto something because I think that is pretty small when compared with the other font. It is not big enough."

CONCLUSIONS

This experiment answered three questions concerning the utilization of route map and turn-by-turn electronic navigation displays:

1. Which display was glanced at more?

2. What driver and road-related factors affected display glances?

3. When did display glances occur?

Which display was glanced at more?

The turn-by-turn display was looked at 3.75 times more often than the route map display. Within this test route, that ratio was dependent on road type, with ratios of 4.5 to 1 for residential, 3.75 to 1 for freeway, and 3.7 to 1 for city.

The location of the display also affected the glance frequency for each display. When the turn-by-turn display was on the right side of the steering wheel (and thus the route map on the left side), over 85 percent of the glances were made to the turn-by-turn display. Conversely, when the turn-by-turn display was on the left, only 72 percent of the glances were made to the turn-by-turn display. Therefore, the preferred display position would be on the right side of the steering wheel, as drivers are most accustomed to looking in that direction (due to climate controls, radios, etc.).

The post experiment evaluation corroborated these results, as the majority of subjects indicated that the turn-by-turn display was used more often and contained the most useful information. Subjects likely responded in this way because of the inherent differences between the turn-by-turn and route map displays. The turn-by-turn display contained many different forms of information that the user could utilize (distance to turn, countdown bar, turn direction arrow, next road), while the route map display only indicated the route and various cross-street names.

The successive display glances revealed the general glance patterns utilized by the subjects. The turn-by-turn display was most likely to be glanced at first, by more than a 3 to 1 margin. Further, once a glance was made to a particular display, the second glance was most likely to the same display.

What driver and road-related factors affected display glances?

Both the age and gender of the subjects affected display glances. Young women and older men had a comparable number of display glances, as did young men and older women. The average number of glances per subject was 291 with a range of 126 to 454. Over the 30.7-mile route (which contained 37 turns), this averaged to about 9.5 total glances per mile for each subject. This result was comparable to a previous on-the-road study that examined route guidance (Green, Williams, Hoekstra, George, and Wen, 1993), where each subject made an average of 11 glances per mile over an 18.3-mile route (which contained 19 turns).

Road type was also a factor that affected the overall display glance rate, as freeway road segments had a low glance rate while city road segments had a much higher glance rate (6.9 and 10.8 glances per mile for each subject, respectively).

When did display glances occur?

Across all segments analyzed by the distance to turn (all freeway segments, long and medium-length city road segments), a general glance pattern emerged. For the turn-by-turn display, a burst of glances usually occurred at the beginning of the segment (within the first 0.2 miles from the previous turn), averaging 12.2 glances per mile for each subject. Then the glance rate for the turn-by-turn display lowered to a steady rate for the rest of the segment, averaging 6.8 glances per mile for each subject, with small bursts of glances occurring at points when the system spoke. Glances to the route map display were relatively uniform throughout each of the segments, averaging 2.0 glances per mile for each subject.

The rate of glances seemed dependent upon the length of the segment. In general, the glance rate (total glances per mile for each subject) decreased as the segment length increased.

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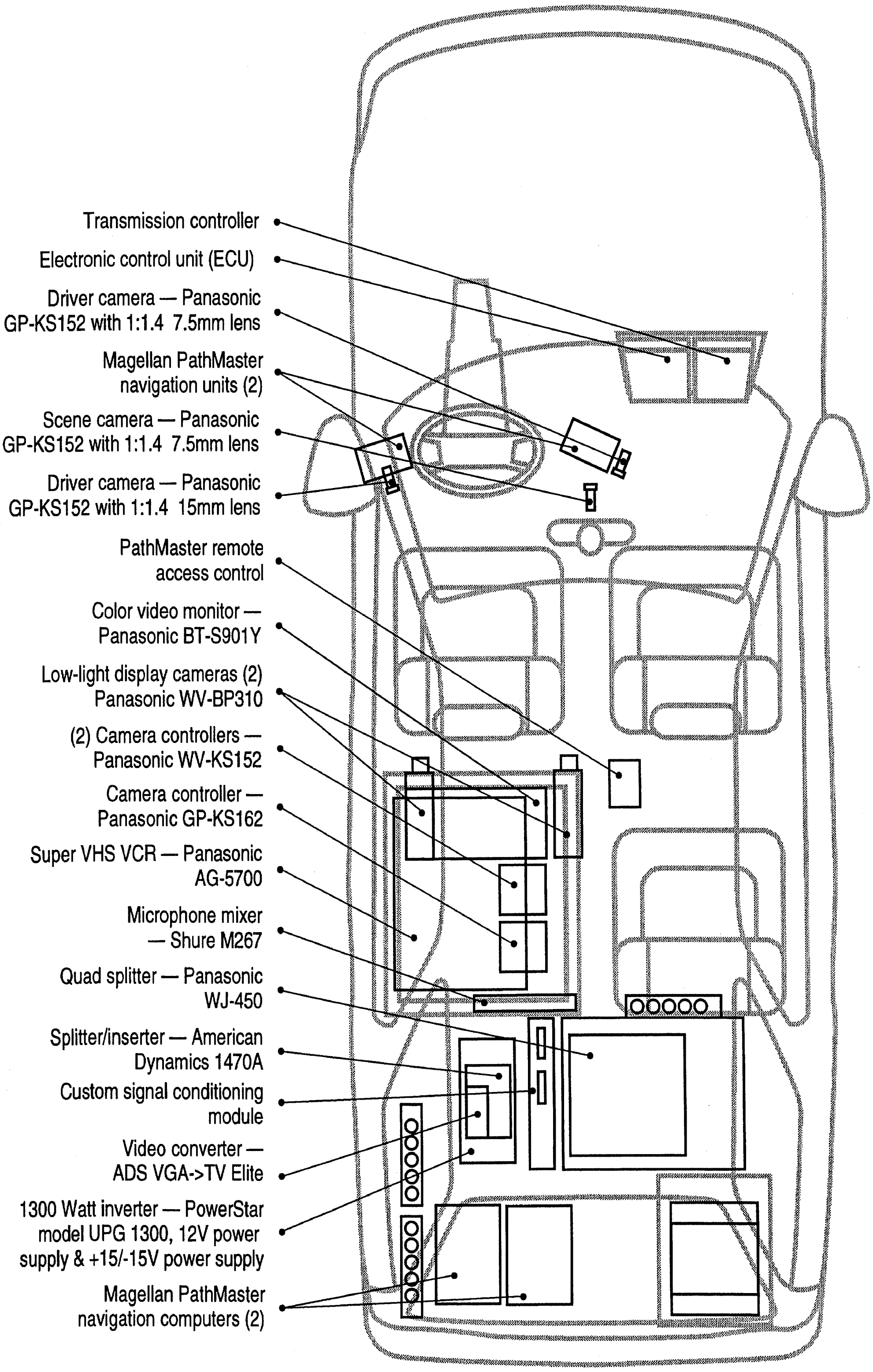
APPENDIX A - Test Vehicle Layout

Driver Interface Research Vehicle
1991 Honda Accord LX Wagon



APPENDIX B - Participant Consent Form

Subject #: ____________

MAP EXPERIMENT - PARTICIPANT CONSENT FORM

Several companies are developing systems that provide electronic maps to guide drivers to destinations along with voice instructions saying where to turn. The purpose of this experiment is to determine when and where various types of displays should be presented to make these systems safe and easy to use for all types of drivers. This is a test of the system, not you, so how well you can read maps, listen to instructions, or other abilities are irrelevant.

You will be driving a Honda Accord station wagon with an automatic transmission and fitted with these systems. An experimenter will also be present as an observer. During the familiarization and data collection phases, follow the guidance provided by the electronic system to reach the specified destinations in and near Ann Arbor. Do so even if you think you know a better way. Data such as speed and lane position will be collected as you drive, and you will be videotaped by several small cameras. Several microphones will be used to record what you say.

The study takes approximately 2 hours to complete, and you will be paid $30 for your time. Thank you for your participation.

****

Your priority is always to drive **safely.** Looking to the navigation system is secondary. You must **obey all traffic and speed laws**. If you are not driving safely, you will be given one warning, after which the experiment can be stopped. Please tell the experimenter at any time if you feel you are unable to complete the experiment.

****

I HAVE READ AND UNDERSTAND THIS DOCUMENT.

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

APPENDIX C - Subject Biographical Form

University of Michigan Transportation Research Institute
Human Factors Division
Biographical Form

Subject: [ ]

Date: [ ]

Name: ______________________

Male **Female** (circle one) **Age:** ________ **Date of Birth:** ___/___/___

Occupation: ______________________

Retired or student: Note your former occupation or major ______________

What kind of car do you drive the most?

Year: ________ Make: ____________ Model: ____________

Approximate annual mileage: ____________

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

No   Yes, in an experiment   Yes, elsewhere

How familiar are you with the roads in the Ann Arbor area?
(1=not at all familiar, 5=very familiar)

1   2   3   4   5

In the last <u>6 months</u>, how many times have you used a map?

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

How often do you use a computer?

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

---

Would you like to be contacted for future studies? Yes No

Phone number: (____) __________

TITMUS VISION: (Landolt Rings)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	Vision correctors? Y / N
T	R	R	L	T	B	L	R	L	B	R	B	T	R	______
20/200	20/100	20/70	20/50	20/40	20/35	20/30	20/25	20/22	20/20	20/18	20/17	20/15	20/13	which?

APPENDIX D - Instructions to Subjects

Phase 4, Map/Turn Displays - Subject Instructions

Hi, are you (participant's name)**? I'm** (experimenter's name)**. Thank you for coming today. Let's go to the conference room and get started.**

Overview
This is done in the conference room.
This study concerns electronic navigation systems for cars and trucks of the future. The information provided today will help make them safe and easy for you and others. The study will take approximately 2 hours to complete and you will be paid $30 for your time. You will be driving a Honda Accord station wagon with an automatic transmission on roads in the Ann Arbor area. Your only task is to follow the route guidance system to several destinations. Obey all traffic laws and speed limits while driving. If you do not drive safely, the experiment will be stopped. During the experiment, you will be videotaped by several small cameras. We will also record what you say.

Before starting, there are some forms you need to fill out. Afterwards, I will give you more detailed instructions.

Bio and Consent Forms
First, please read and sign this consent form, and then fill out the biographical form. If you have any questions feel free to ask them at any time.

Provide consent and biographical forms. Check that it is legible and complete.

It is necessary to check your eyesight before beginning the experiment.

Vision Test
Do you use any corrective eyewear while you drive? If subject answers yes - **Could you please put them on?** Subject puts face up to vision tester. **Can you see that there are many numbered diamonds, and in each diamond there are four circles? And that one circle is complete and the other three are broken? In each diamond, tell me the location of the complete circle - top, bottom, left, or right. Start with number 1 and continue down the line.** Continue until 2 in a row are wrong. Take the last one that was correct as the visual acuity.

I also need to see your driver's license. Check license.

OK, we can now go down to the test vehicle.

At the Test Vehicle (while still at UMTRI)
(sit up front)

This is a study to determine when drivers want map displays and when they want turn-by-turn displays while being guided to an unknown destination. For some systems, only one small screen will be provided. The idea is for the system to know what drivers want and automatically switch to the desired display type at just the right time.

This experiment will take place on roads in the Ann Arbor area. You will drive on freeways, rural roads, one-way and two-way city roads, and residential roads. Your task is to follow the route guidance system to a specified destination unknown to you. Once the target destination is reached, I will set the next destination and ask you to again follow the guidance system to reach that destination.

During this experiment, a turn-by-turn display will be shown on the display to your [left/right] **and a route map will be shown on the display to your** [right/left]. Location is counterbalanced between subjects -- switch as appropriate. **This is an example of a turn-by-turn display.** Show subject graphic, making sure to point out the road name, turn indication, distance to turn, and countdown bar. **When you are about two-tenths of a mile from a turn, this bar will appear and it will shrink as you get closer to where you need to turn. Once the turn is made, it will disappear. Also, the unit will speak to you for instruction on a turn.**

This is an example of the route map. Show subject graphic of route map, making sure to point out the location icon and the route indicator. **The route will be highlighted in red. Sometimes the map will be oriented so north is at the top. Sometimes it will be aligned so the direction in which you are heading is at the top. As you drive, the scale will change so you will be able to see the next turn. Do you have any questions about what will be shown on each display?** Answer any additional questions.

To familiarize you with the route guidance system and the data collection procedure, the first two destinations will both be practice. After the second practice destination is reached, another destination will be entered and you will drive to it.

Finally, during the first two practice destination runs, I can answer any questions that you might have. Also, as you drive, you are encouraged to comment on the guidance--the content of the screens, information you would like to have, information you do not need, how you are deciding to turn, and so forth.

Do not turn off the vehicle at any point during the experiment. When we must stop to change destinations, you can simply put the car in "park."

Let me reiterate a few important points from the consent form. First of all, driving safely is your main priority. If you feel unsafe or unable to make any turn, do not do it. Otherwise, use the guidance provided by the navigation system. Second, if you are uncomfortable or wish to stop at any time, please let me know right away. You are expected to obey all speed limits and driving laws, and they have priority over the navigation system. It should not ask you to do anything illegal.

Please fasten your seat belt, adjust the seat, mirrors, steering wheel height, as you feel necessary.

- Adjust the car seat, steering wheel height, and side and rearview mirrors.
- Fasten seat belt.
- Point out climate controls, the radio may not be operating during experimentation.
- Remind about following speed limit.
- After Honda is started, turn on the toggle switch to "inverter" (right switch) and turn inverter on (left switch), then turn on 2 power strips and the VCR.
- Adjust eye fixation cameras once subject is comfortable.
- Make sure that both displays are on the 1/4 mile scale to start.
- Make sure the voice is ON for the turn display and OFF for the route display.
- Tape route/turn indicator to back of passenger seat before starting.

If you have no further questions, then we can get started.

Hop in back and start videotape.

<u>On the Road</u>

Enter all destinations as the "Shortest Route," except for test destination 2, Wing Dr., which must be input as the "Least use of Freeways".

Before the first destination can be input, we need to calibrate the system. So, we will drive around the block once before I input the first practice destination. Whenever you are ready, you can go down this drive and turn left. Continue down this road to the end and turn right. OK, now turn right on the next street. OK, now just continue down this road while I input the first practice destination. Enter 450 Pine Brae. **OK, now you can follow the route guidance system.**

1st practice destination reached. **OK, you can just drive up a little ways and then pull over anywhere on the right-hand side of the street and park the vehicle.** Subject parks. **I am now entering the second practice destination. Do you have any questions after the first practice destination?** Enter 2nd practice destination, 5100 Church Rd. **OK, you may proceed whenever you are ready.** Once subject begins driving, switch [left/right] display to the route map.

2nd practice destination reached. **OK, you can just pull over anywhere on the right-hand side of the street and park the vehicle. That concludes the**

practice session. I am now going to input the first test destination. Enter 1421 Creal Crescent. **Do you have any questions before we begin the actual testing?** Answer any questions the subject may have. **OK, you may proceed whenever you are ready.** Once subject begins driving, switch [left/right] display to the route map.

1st test destination reached. **OK, you can just pull over anywhere on the right-hand side of the street and park the vehicle. I am now going to enter the second test destination.** Enter 1150 Wing Dr. with the **LEAST USE OF FREEWAYS**. **OK, you may proceed when ready.** Once subject begins driving, switch [left/right] display to the route map.

En Route: prior to Miller/Wagner intersection. **This is a 4-way stop ahead so be a little extra careful.** Prior to Zeeb/Dexter intersection. **This is another 4-way stop ahead so again be a little extra careful.**

2nd test destination reached. **OK, you can just pull over anywhere on the right-hand side of the street and park the vehicle. I am now going to enter the next destination.** Enter 2750 S. Industrial. **OK, you may proceed when ready.** Once subject begins driving, switch [left/right] display to the route map.

En Route: At I-94 entrance ramp. **This entrance can be very busy, so be patient when merging.** At State St. **When you make this turn, you must merge with moving traffic, so be careful.**

3rd test destination reached. **OK, I will guide you in from here. Do you see the MediaOne sign to the right? Pull in the drive just past it on the right.** Subject turns right. **Now make a quick left over by those pine trees. Now you can just park the vehicle right here. I am now going to enter the next destination.** Enter 2150 Brockman. **OK, you may proceed when ready.** Once subject begins driving, switch [left/right] display to the route map.

4th test destination reached. **OK, you can just pull over anywhere on the right-hand side of the street and park the vehicle. I am now going to enter the next destination.** Enter 1099 Maiden Lane. **OK, you may proceed when ready.** Once subject begins driving, switch [left/right] display to the route map.

5th test destination reached. **OK, I will guide you in from here. Do you see the parking lot to the right? Pull in the first drive there and park under the tree.** Enter 2901 Baxter Rd. **OK, you may proceed when ready. Watch for people walking along the sidewalk.** Switch [left/right] display to the route map.

Once subject arrives at UMTRI. **OK, we have arrived back home. You can go straight here and then turn left here** (UMTRI entrance). **You can just park it right where we started from. You can leave the car running.**

Back At UMTRI

Now I would like to ask you some questions about the experiment. Use evaluation form to ask subjects the questions. Videotape the conversation so that the subject does not need to write things down. Stop videotape when evaluation is complete.

If you could fill out this form, I will pay you for your time.

Take tape out of VCR before shutting down. Fill out form and give compensation.

Thank you very much for participating today. Have a nice day.

APPENDIX E - Zoom Level Settings

Zoom levels to be used during the experiment. Change the route map to the appropriate map scale at the specified location.

Dest.	Road	Map scale (mi)	Press
P1	Leave on 1/4 mi		
	Geddes	1	+
	0.3 mi from Geddes/Earhart	1/4	-
	Leave on 1/4 mi		
P2	Earhart	1	+
	0.3 mi from Earhart/Plymouth	1/4	-
	Plymouth	1	+
	0.3 mi from Plymouth/Dixboro	1/4	-
	Leave on 1/4 mi		
T1	Plymouth	1	+
	0.3 mi from Plymouth/US-23 entrance	1/4	-
	after Merge	1	+
	after 2nd Merge	4	+
	1.3 mi from M-14 exit	1	-
	On M-14 exit	1/4	-
	after Merge	1	+
	On Miller/Maple exit	1/4	-
	Leave on 1/4 mi		
T2	On Miller	1	+
	0.3 mi from Miller/Zeeb	1/4	-
	Leave on 1/4 mi		
T3	after Merge	1	+
	after M-14 exit is passed	4	+
	1.6 mi from State (at Ann Arbor/Saline exit)	1	-
	at State St. exit	1/4	-
	State St.	1	+
	0.3 mi from State/Eisenhower	1/4	-
	Eisenhower	1	+
	0.3 mi from Eisenhower/Industrial	1/4	-
	Leave on 1/4 mi		
T4	On Industrial	1	+
	0.3 mi from Industrial/Stadium	1/4	-
	On Stadium	1	+
	0.3 from Stadium/Brockman	1/4	-
	Leave on 1/4 mi		
T5	On Washtenaw	1	+
	0.3 mi from Washtenaw/Zina Pitcher	1/4	-
	Leave on 1/4 mi		
T6	On Plymouth	1	+
	0.3 mi from Plymouth/Huron Pkwy	1/4	-
	Leave on 1/4 mi		

APPENDIX F - Post experiment Evaluation

Name: ______________________ Date: _______________

Subject#: __________

MAP STUDY
POST-EXPERIMENT EVALUATION

Instructions: Experimenter reads these questions to subject while videotape is running.

Which display did you use most often?

turn-by-turn route map

Which display had the most useful information?

turn-by-turn route map

What information was most critical for guiding you to the destination?

How did you decide when to look at the map and when to look at the turn display?

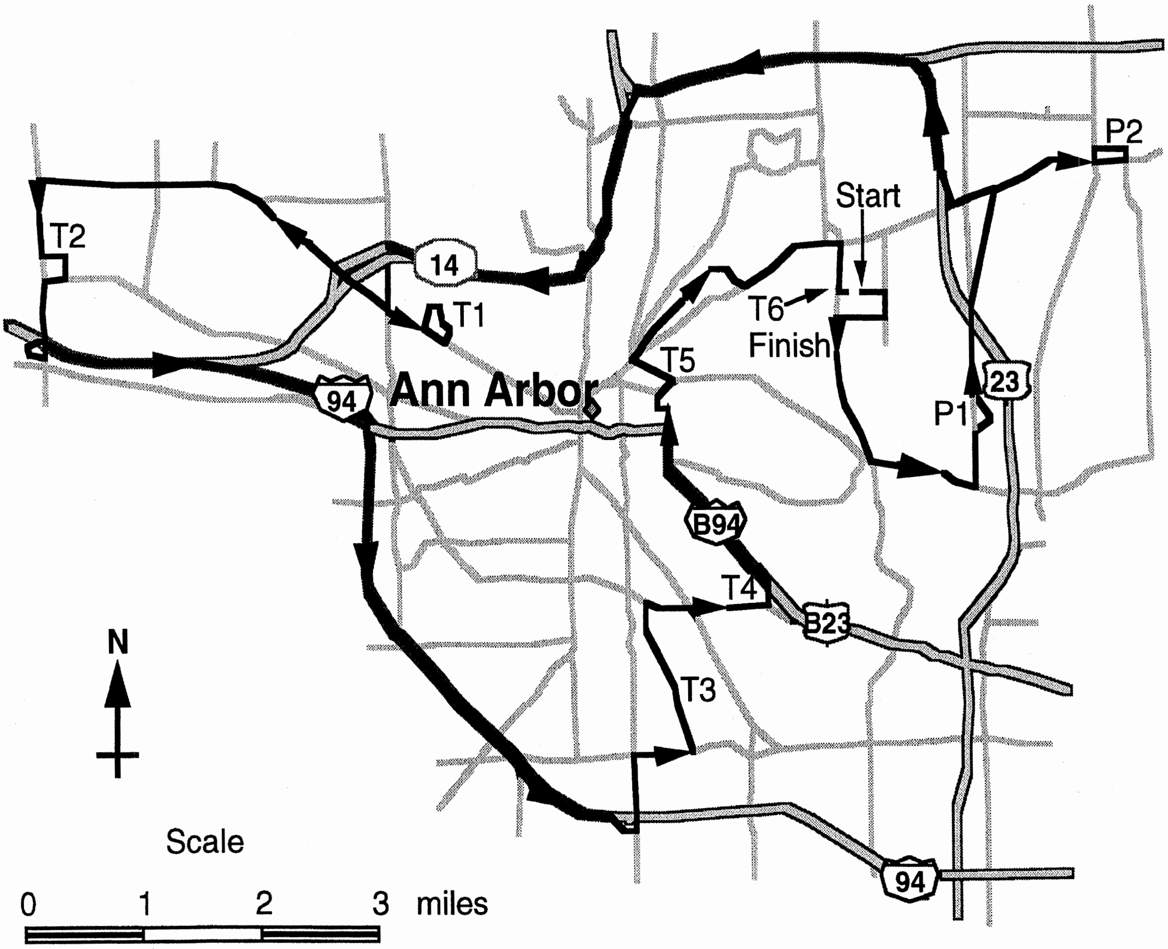
Was the area shown on the map (the number of miles of coverage, not the screen size) always set to what you wanted or expected?

Yes No If No, please explain how it should be changed.

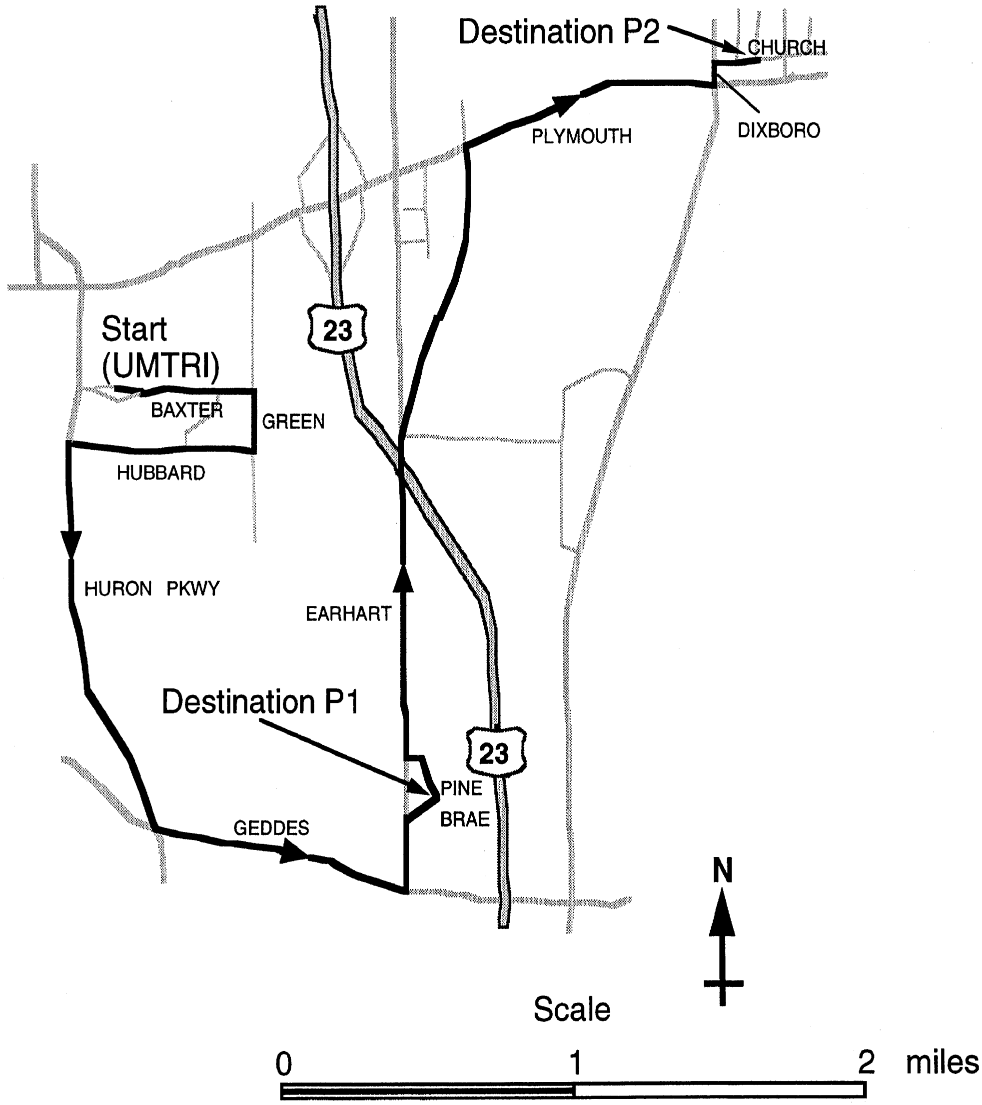
What did you like or dislike about the system?

Do you have any additional comments?

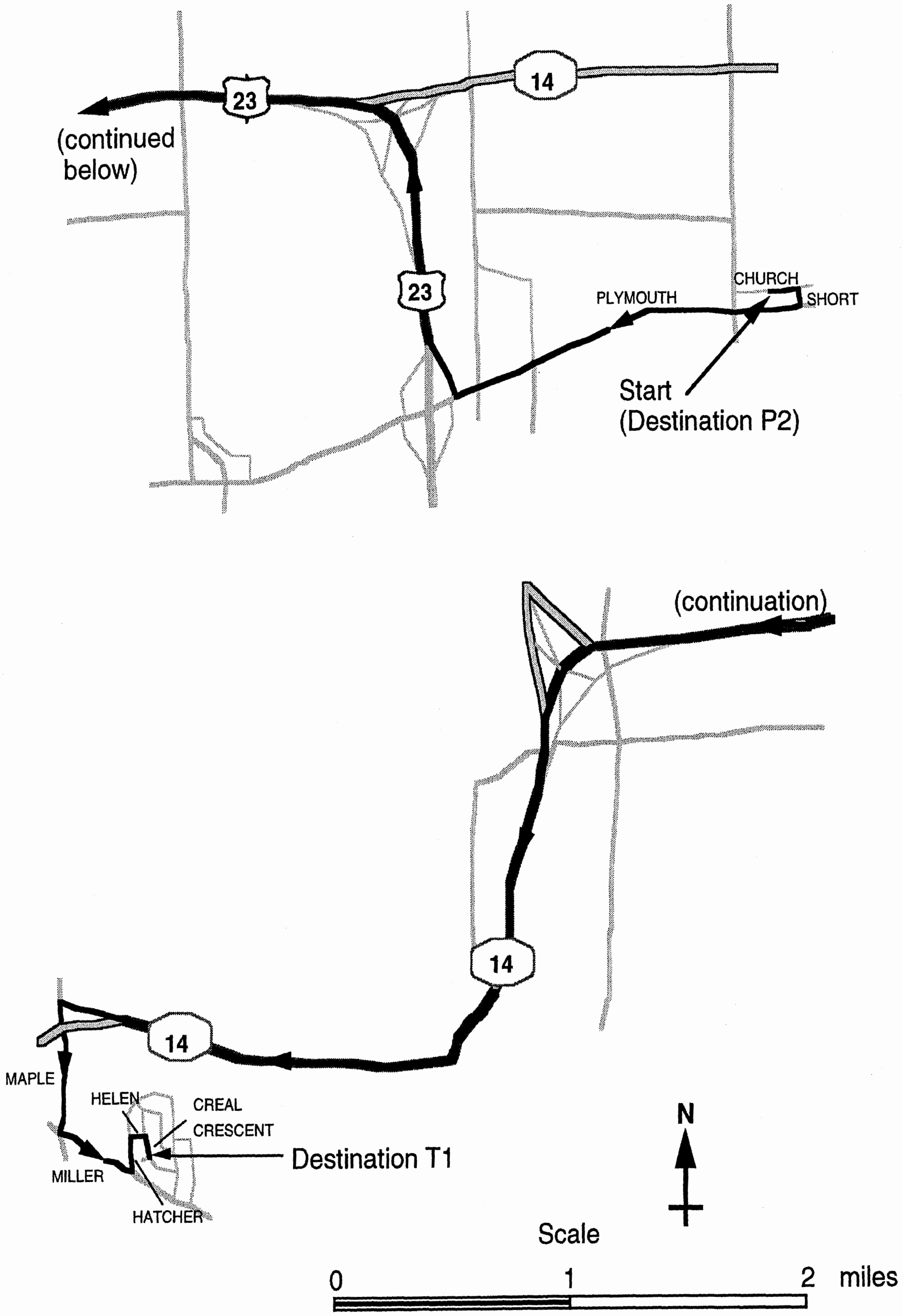
APPENDIX G - Experimental Route



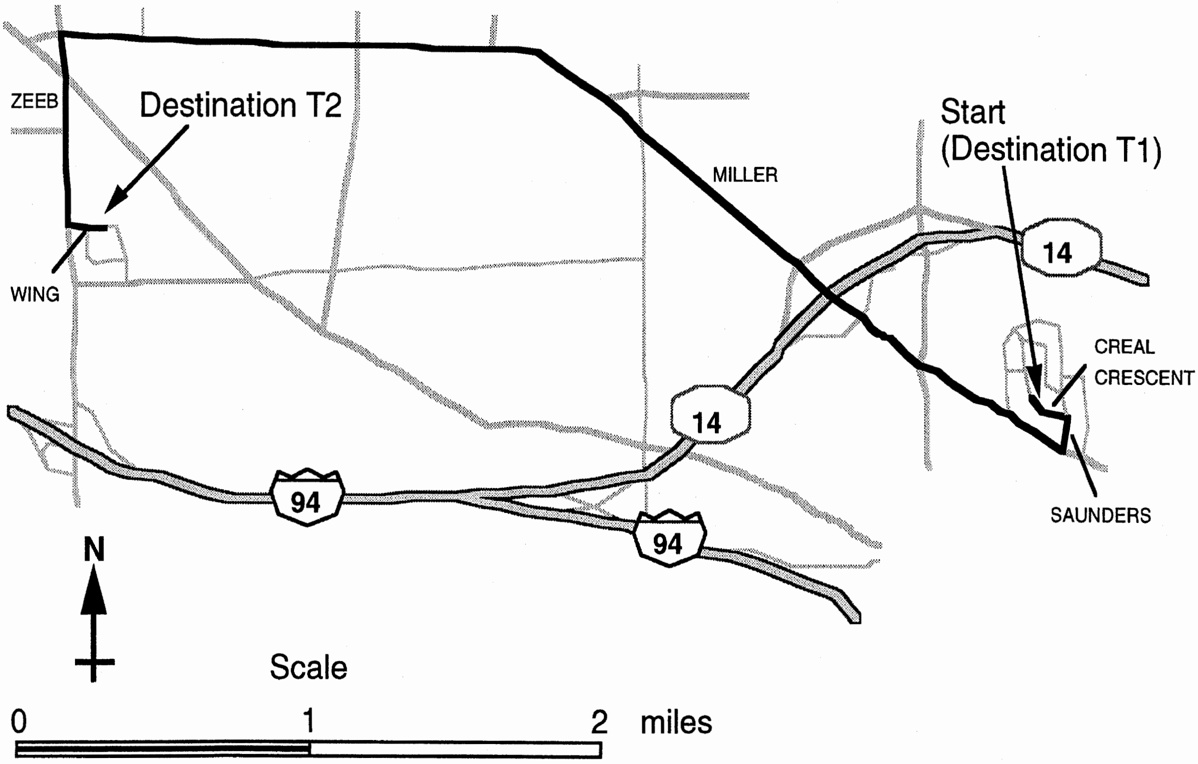
Overall Route



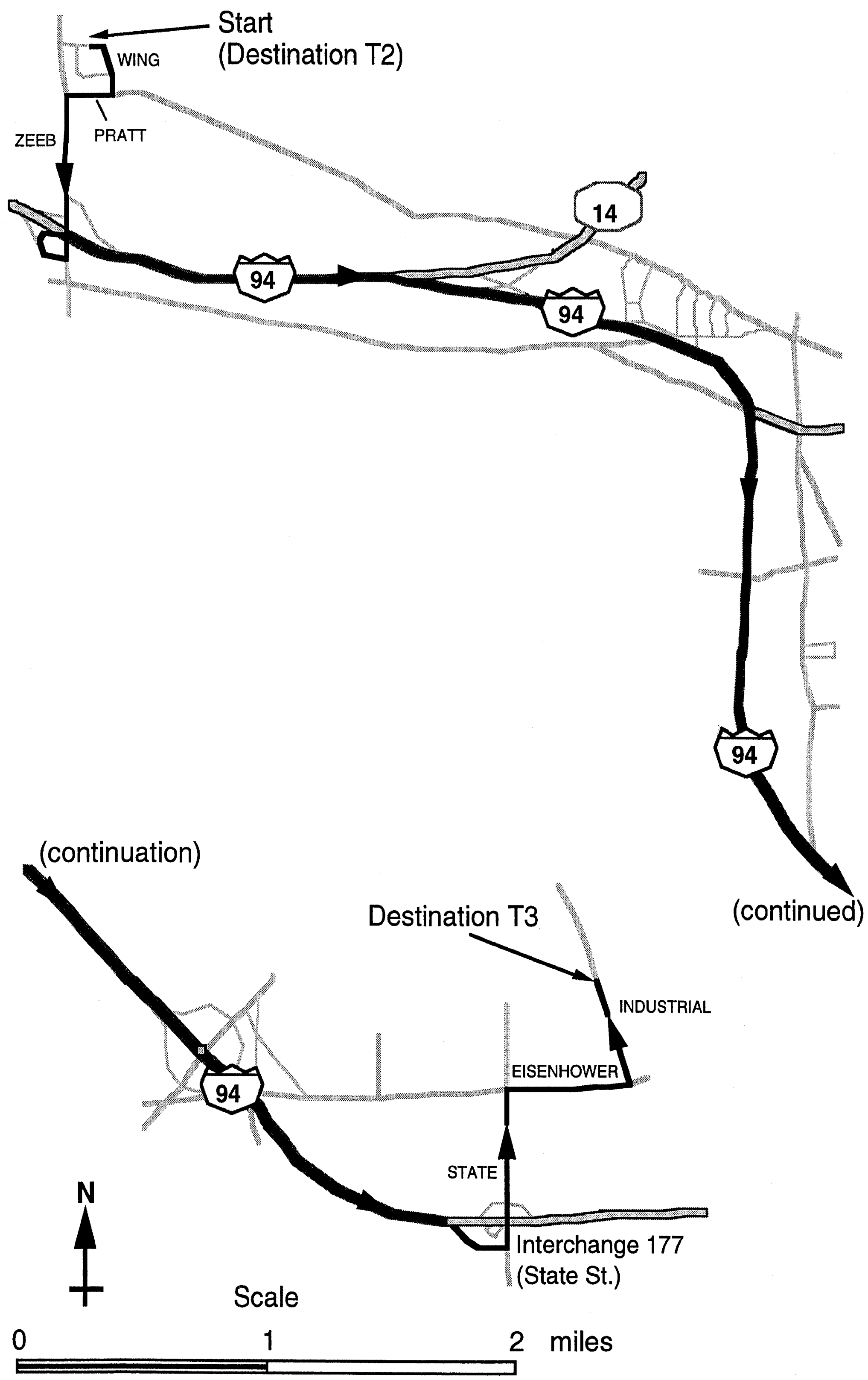
Practice Destinations



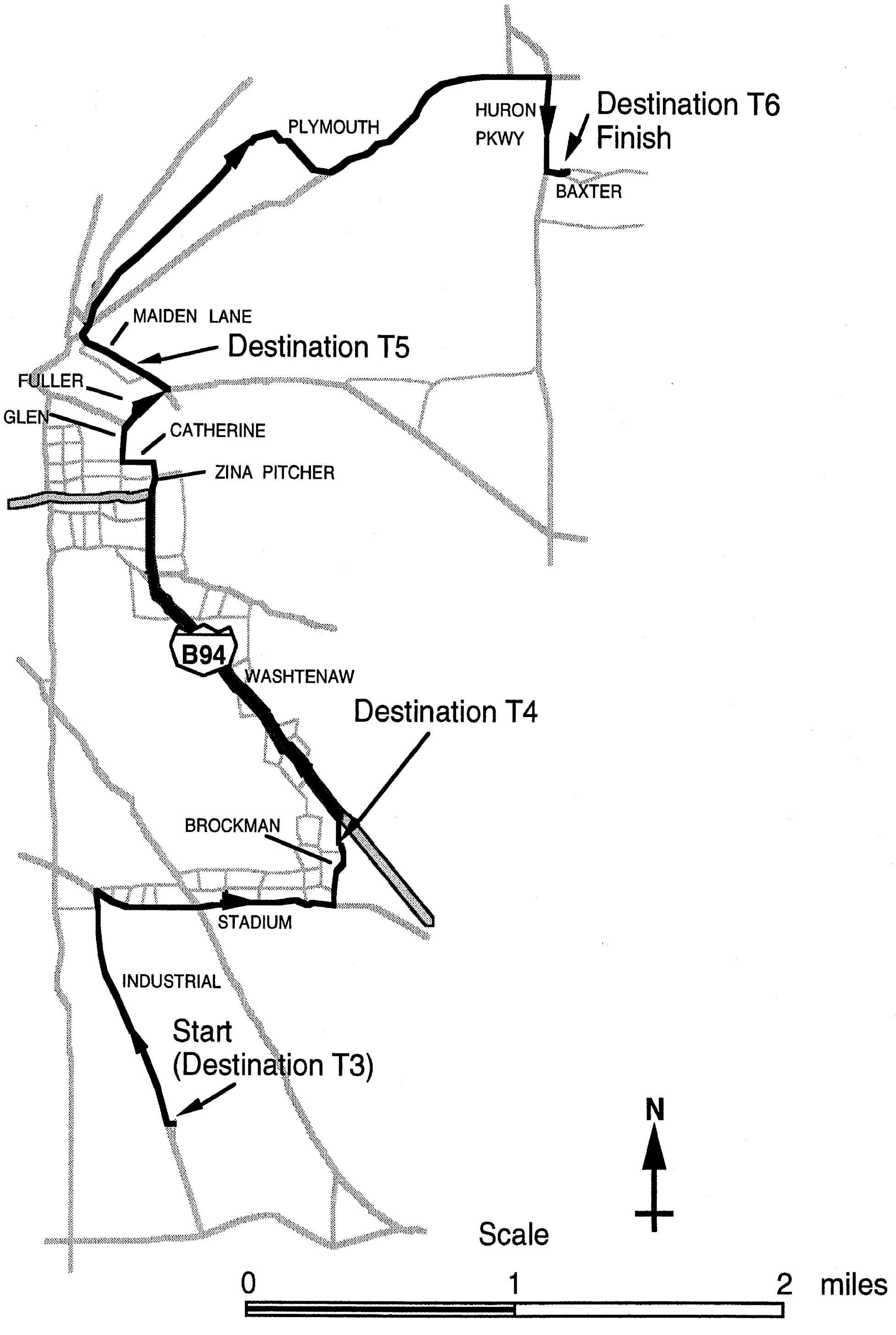
Test Destination 1



Test Destination 2

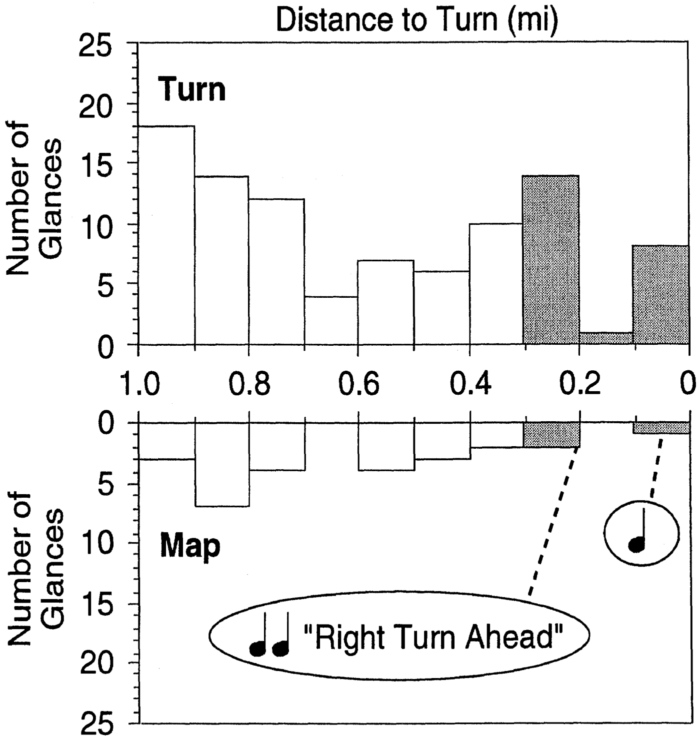


Test Destination 3

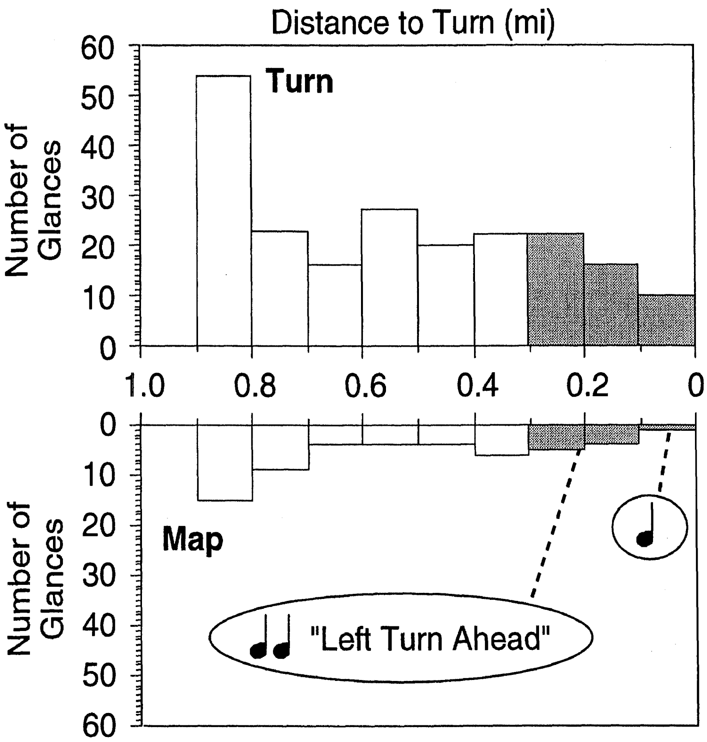


Test Destinations 4, 5, and 6

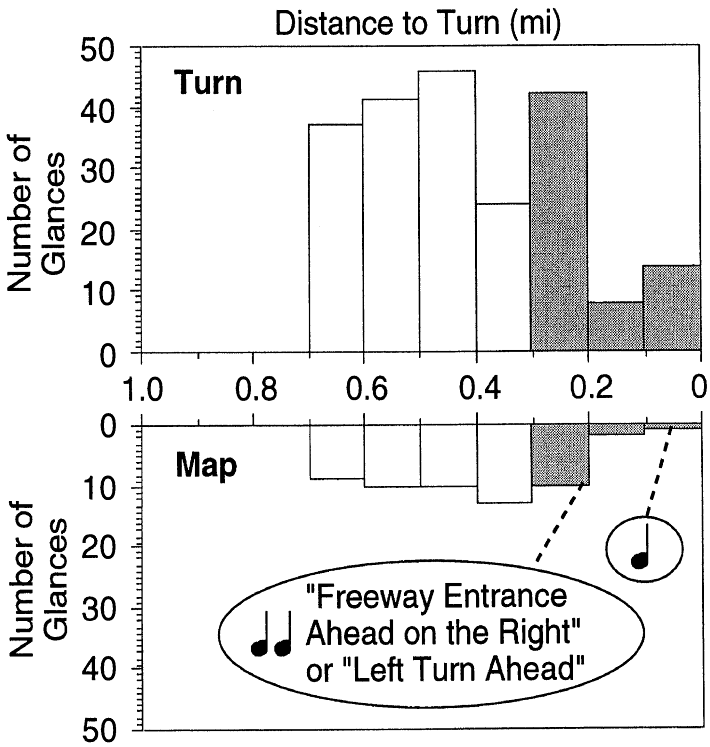
APPENDIX H - Additional Graphics for Medium City Road Segments



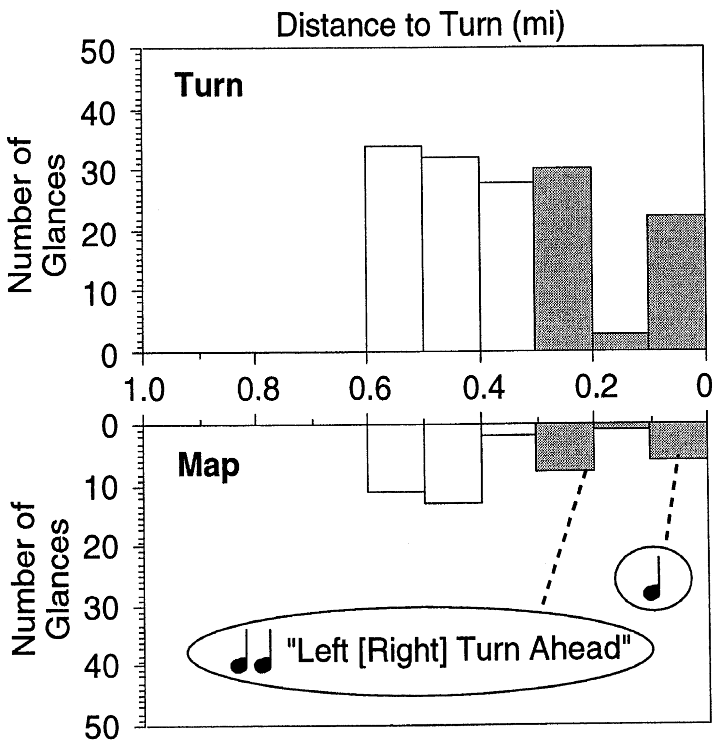
Distance to turn for one medium (0.9-mile) city road segment.



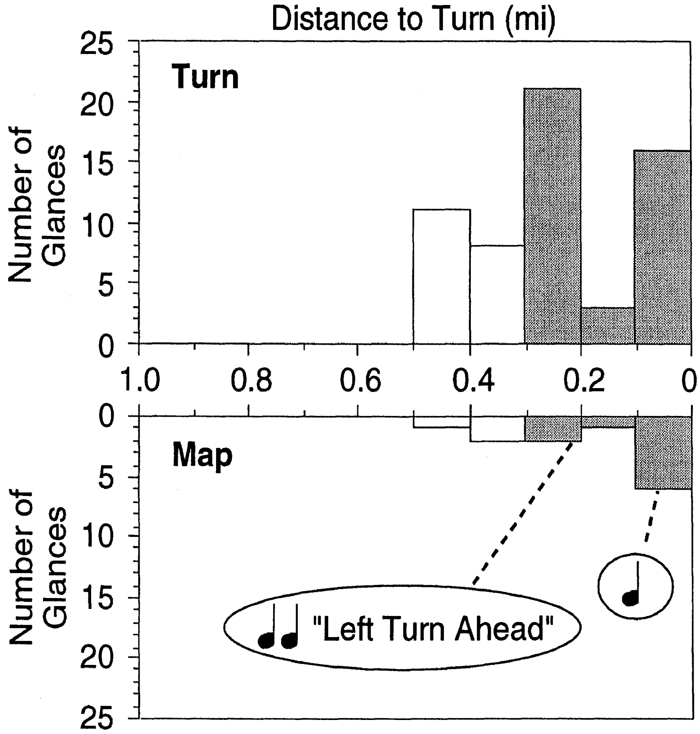
Distance to turn for one medium (0.8-mile) city road segment.
Note: this graphic has a different scale than all the others.



Distance to turn for two medium (0.6-mile) city road segments.



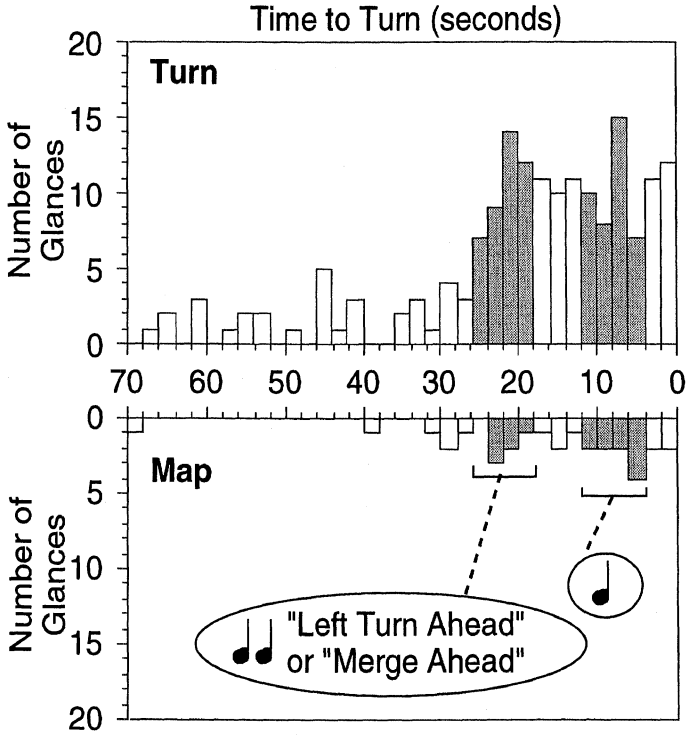
Distance to turn for two medium (0.5-mile) city road segments.



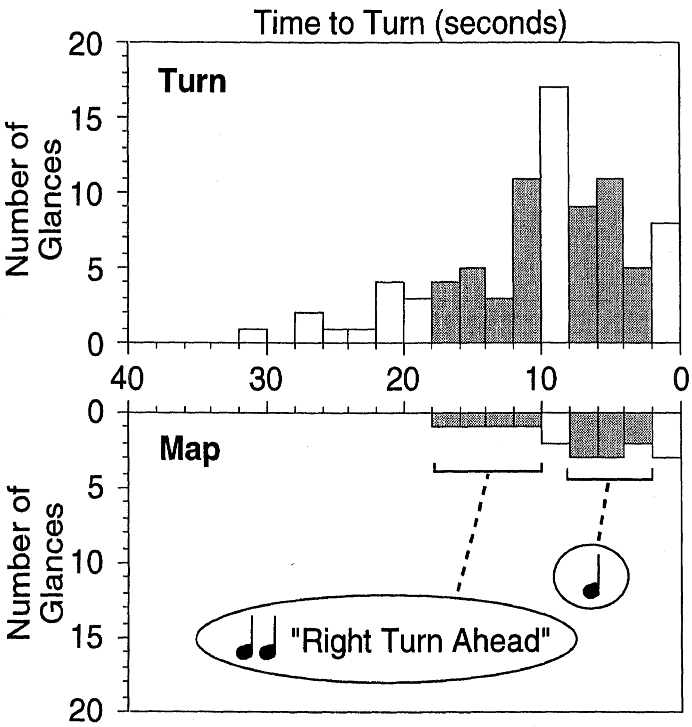
Distance to turn for one medium (0.4-mile) city road segment.

APPENDIX I - Additional Graphics for Short City Road Segments

One of the 0.1-mile segments contained a traffic light for which some subjects had to stop. This was a confounding factor for the time to the turn on the distribution below.



Time to turn for three short (0.1-mile) city road segments.



Time to turn for two short (0.0-mile) city road segments.

APPENDIX J - Markov Matrix Calculations

Given: a successive glance event occurs

Zero-order (M_0)

Turn

189 (Table 14; 984 - 795 = 189)
+ 344 (Table 14; 1313 - 969 = 344)
+ 196 (Table 15; first glances to turn display)
----
729 (total number of first glances to turn display)

Map

24
+ 43
+ 75
----
221 (total number of first glances to map display)

Total: 729 + 221 = 950

Probability of initially looking to: *Turn:* 729/950 = 76.7%
Map: 221/950 = 23.3%

First-order (M_1)

Turn-Turn

189 (Table 14; 984 - 795 = 189)
+ 344 (Table 14; 1313 - 969 = 344)
+ 103 (Table 15; 196 - 93 = 103 [93 = turn-map glances])
----
636 (glances to turn then turn)

Turn-Map 93 (glances to turn then map)

Map-Turn 79 (glances to map then turn)

Map-Map

24 (Table 14; 984 - 795 = 189)
+ 43 (Table 14; 1313 - 969 = 344)
+ 75 (Table 15; 154 - 79 = 75 [79 = map-turn glances])
----
142 (glances to map then map)

Total (turn-turn, turn-map): 636 + 93 = 729
Total (map-turn, map-map): 79 + 142 = 221

Probability of looking to: *Turn then Turn:* 636/729 = 87.2%
Turn then Map: 93/729 = 12.8%
Map then Turn: 79/221 = 35.7%
Map then Map: 142/221 = 64.3%