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April 1999

Preliminary Examinations of the Time to Read Electronic Maps: The Effects of Text and Graphic Characteristics

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HUMAN FACTORS

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16. Abstract

This report is the first in a series examining the time to read electronic maps while driving. The 20 subjects that participated, 10 young (ages 18-30) and 10 older (ages 65+), drove the UMTRI Driving Simulator while performing one of three map-reading tasks: (1) identify the street being driven, (2) find the name of a cross street ahead, and (3) locate a particular street. Response times and errors were collected.

Four factors were varied: (1) the number of streets displayed (6, 12, and 24), (2) the street name label size (12 and 18 point), (3) the street name orientation (horizontal, vertical, and stacked), and (4) the street layout of the electronic map (grid and non-grid). In this experiment, every street on the map was labeled with a name.

Overall, Task 1 (On-street) had the lowest mean response time (1.8 seconds) and error rate (7.1%), and Task 3 (Where is?) had the highest mean response time (4.3 seconds) and error rate (14.5%). Age had a large effect on response times, with responses from older subjects being 23% to 35% longer. Beyond 12 labeled streets, error rate and response times greatly increased. Overall, 18 point was the best street name label size, although clutter effects were observed when more than 6 labeled streets were shown. Maps with vertical streets labeled horizontally led to the highest response times and error rates, while vertically labeled streets had the lowest.

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UMTRI Technical Report 98-36, April 1999
Aaron Brooks, John Lenneman,
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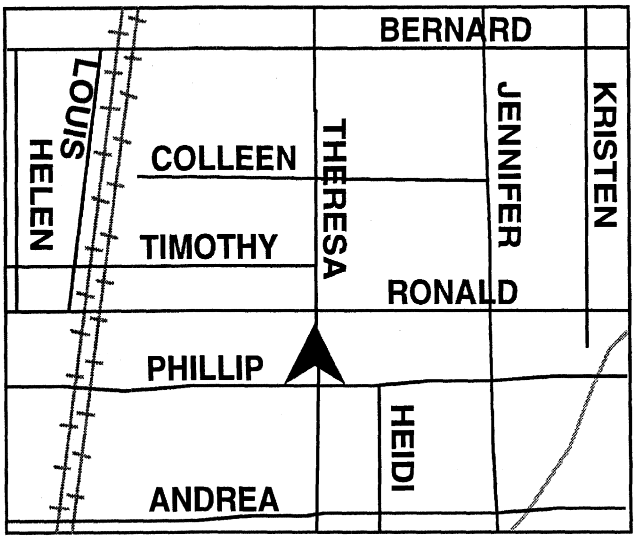
Ann Arbor, Michigan, USA

1 ISSUES

1. How many streets should be shown on an in-vehicle map display?
2. What size text should be used for the street labels?
3. What orientation should be used for street names on an in-vehicle map display?

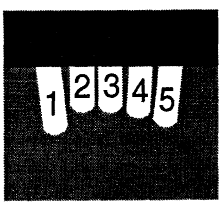
2 MAP TASKS

Sample Map



(12 point, 12 streets, vertical text, grid map)
(80% of actual size)

Keypad Responses



Note:
only necessary response keys were visible during each task

Task 1 - On-Street
2 = male
3 = female

Task 2 - Cross Street
1 = not there
2 = male
3 = female

Task 3 - Where is?
1 = not there
2 = ahead 4 = left
3 = behind 5 = right

***Task 1* - On-Street**

What street are you on?
Subject Finds: Theresa
Responds: female (**3** key)

***Task 2* - Cross Street**

What is the 1st Cross Street?
Subject Finds: Ronald
Responds: male (**2** key)

What is the 3rd Cross Street?
Subject Finds: Colleen
Responds: female (**3** key)

What is the 6th Cross Street?
Subject Finds: only 4 streets
Responds: not there (**1** key)

***Task 3* - Where is?**

Where is Bernard?
Response: ahead (**2** key)

Where is Andrea?
Response: behind (**3** key)

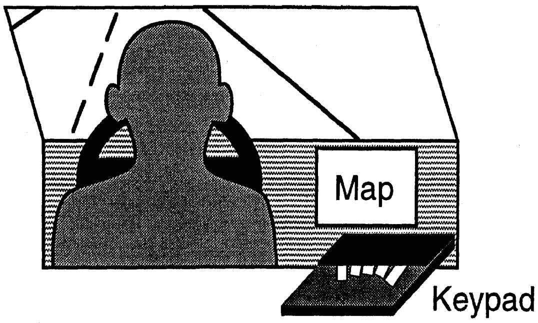
Where is Helen?
Response: left (**4** key)

Where is Jennifer?
Response: right (**5** key)

Where is Douglas?
Response: not there (**1** key)

3 METHOD

Simulator Driving Scenario



Subjects (n = 20)

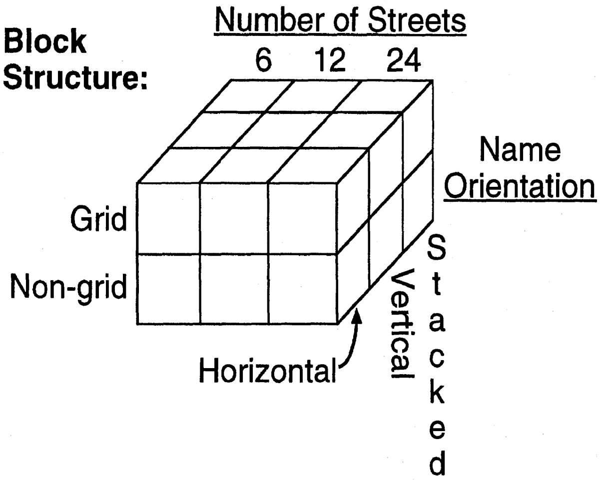
Block Order	Young		Older	
	Men	Women	Men	Women
12pt → 18pt	**3**	**2**	**3**	**2**
18pt → 12pt	**2**	**3**	**2**	**3**

Subjects were shown either the 12-point or 18-point block first, balanced over age and gender.

Main Test Conditons

Two blocks: **12-POINT BLOCK** and **18-POINT BLOCK**

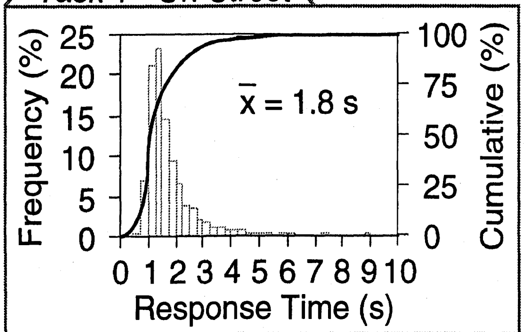
Block Structure:



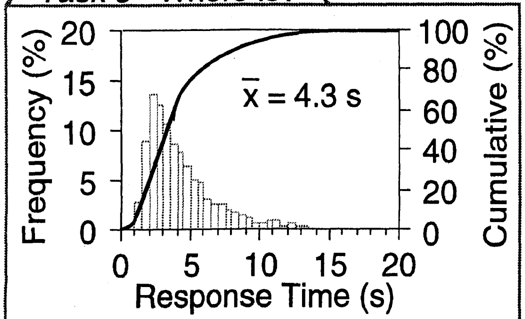
4 RESULTS and CONCLUSIONS

Response Time (RT) and Error Rate

Task 1 - On-Street

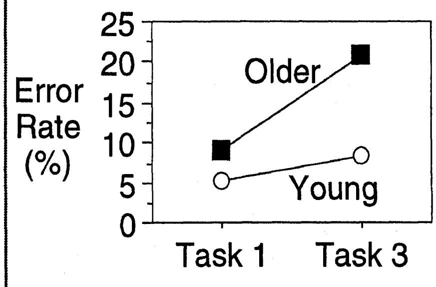


Task 3 - Where is?



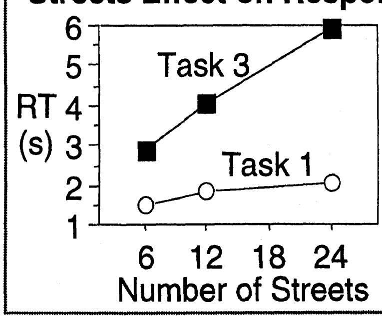
Task Differences

Age Effect on Error Rate



For Error rate, age differences increase as task difficulty increases

Streets Effect on Response Time (RT)

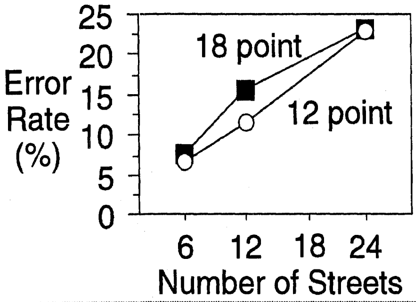


Streets effect on RT:
Task 1 = 31 ms/ street
Task 3 =167 ms/ street

Issue 1 - How many streets to display? and Issue 2 - What size text to use?

Task 2: Streets by Point Size Effects (1st cross-street only)

Task 1: Streets by Point Size Effects

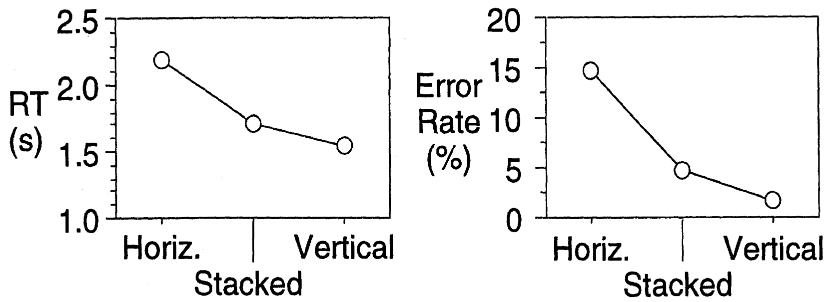


Recommendations:

1. Display ≤ 12 labeled streets
2. Only use 18 point with very few labeled streets (6 or less); otherwise use 12 point (when only 12 and 18 point are available)

Issue 3 - What street name orientation to use?

Task 1: Name Orientation Effects



Recommendations:

1. Use vertical, if possible
2. Do **not** use horizontal to label vertical streets (RT longer, error rate higher)

Response Time Regression Equations

Task 1: On-Street	RT (ms) = 1334 + 264*(A) + 31*(S) + 378*(Or) + 168*(A)*(Or) + 35*(S - 14)*(Or)
Task 3: Where is?	RT (ms) = [2850 + 572*(A) + 116*(S) - 44*(P) + 5*(A + 0.5)*(S - 9)*(15 - P)] * SR

Terms for Regression Equations

$$A = \text{Age}\begin{cases}-1 \text{ if Young}\\ +1 \text{ if Older}\end{cases}$$

$$SR = \text{Search Result}\begin{cases}1.0 \text{ if found}\\ \left(\dfrac{10+S}{12+\ 0.5*(S)}\right) \text{ if not found}\end{cases}$$

S = Number of Streets ($S \geq 1$)

P = Point Size ($12 \leq P \leq 18$)

$$Or = \text{Name Orientation}\begin{cases}+1 \text{ for horizontal}\\ -.28 \text{ for stacked}\\ -.72 \text{ for vertical}\end{cases}$$

PREFACE

This research was funded by the University of Michigan Intelligent Transportation Systems (ITS) Research Center for Excellence, formerly the IVHS 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.

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 five reports summarized on the next page:

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

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. At the time the project began, 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, etc.

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).

This report summarizes the initial 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 the street layout.

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 experiment 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 experiment 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

Under the banner of Intelligent Transportation Systems (ITS) and other names, there is a major worldwide research and development program to improve transportation. One of the major innovations of the program is the installation of electronic navigation systems. Such systems are now widespread in Japan and are beginning to appear in rental and new cars in the U.S. and in Europe. Drivers provided with directions (via a visual display, spoken directions, or both) are less likely to get lost and will be able to avoid congestion when traffic information is available. Such systems will provide operational benefits such as reduced congestion and less wasted travel time, make driving safer by routing drivers around dangerous situations, and in general, make driving more pleasant.

Customers want navigation systems that are safe and easy to use. Manufacturers want products that satisfy customers, meet existing and anticipated government regulations and accepted design guidelines (Carel, Hershberger, Herman, and McGrath, 1974a,b; Green, Levison, Paelke, and Serafin, 1995), and minimize potential product liability litigation. A major concern is that if maps are difficult to read, drivers will attend to them and not the road ahead. If attention to the road scene is diminished, opportunities for crashes will increase. Research that addresses this concern appears in a technical report (Wierwille, Hulse, Fischer, and Dingus, 1987). Summaries appear in three proceedings papers (Wierwille, Hulse, Fischer, and Dingus, 1988; Hulse, Dingus, Fischer, and Wierwille, 1989; Wierwille, Hulse, Fischer, and Dingus, 1991).

At the outset of this project, there was almost no research specifically focused on the time to read maps as a function of the factors of interest to automotive engineers. (See Green, 1999, the first report of this project, for a review. For a review of some of the research on navigation displays, see Green, 1992.)

Initially, this project only uncovered one experiment relating street map characteristics to user performance. Stiltz and Yitzhaky (1979) had 125 subjects point to locations on a street map of Jerusalem after being given a name. (Some details concerning the task and map, such as the area covered, were not provided). The target location time (T) was estimated by 6.55 + 1.2(1/GLS) + 0.36n where GLS, the grid line separation, was 0.2, 0.25, 0.33, 0.5, and 1.0 kilometers (km), and n was the average number of roads per grid square. In a second experiment, 50 people located coordinates on the same set of maps. Using the combined data, the time to locate a street within a grid was equal to 2.1 + .38n, where n was the number of roads in the grid (range of 4 to 25). Hence, according to these data, an additional 0.4 seconds is required for each street added to a map (for 4 or more roads).

This lack of data, coupled with a concern for excessive reading times, led to this project. Interestingly, published studies on this topic did not appear in the open Japanese literature prior to the wide-scale production of map-based navigation systems. In Japan, low driving speeds (often stopped due to congestion), a more favorable litigation environment, and the immediate need for this product delayed attention to human factors issues. (In Japan, streets may not be named and buildings are numbered chronologically, so navigation without a map can be a challenge.)

The objective of this project was to develop a series of models which predict the time required for various map-reading tasks as a function of product characteristics, the user's task, and user differences. Accordingly, the following issues must be addressed:

How do response time and errors in reading a map vary with

1. the road graphics (the number of roads shown, color or width coding, grid vs. non-grid, etc.);
2. the road label design (percent of roads labeled, orientation, character size, etc.);
3. the display location (various locations in center console, etc.);
4. the task performed (identify the road being driven, identify a cross road, find a road on a map, etc.);
5. differences between drivers (due to age, gender, and individual differences)?

For this project, response time was the primary performance measure because it was more likely to be sensitive to the design differences of interest than error rate, since times are continuous and errors are binary. However, it is important to verify that in responding to maps, drivers do not trade off measures (for example, long response times do not occur simply because drivers spend more time attending to the primary task of driving, so lane position and speed are less variable, speed is greater, etc.).

To make this project manageable, the issues of interest have been partitioned across a series of experiments. The general approach is to collect the initial data sets in a driving simulator, and then subsequent data on the road, repeating some conditions in both contexts so the simulator data can be scaled to predict on-the-road performance.

This phase of the project addressed four key issues relevant to the scope of the entire project:

1. How many streets should be shown on an in-vehicle map display?
2. What size text should be used for the street labels on an in-vehicle map display?
3. What orientation should be used for street names on an in-vehicle map display?
4. What is the effect of the street layout of a map on an in-vehicle map display?

MAP DEVELOPMENT

For this project, a set of test maps was developed that (1) represented what drivers would encounter while driving in the U.S. and (2) served the design goals of the experiment. To develop the 96 test maps used in the initial studies (Appendix A) the following questions had to be answered:

1. How many streets and other objects should be shown and how should they be arranged?
2. What names should be used for the streets?
3. How should the street names appear on maps?
4. How should subjects signal their answers to the experimenter? (Although this question may seem slightly irrelevant, the answer impacts question 3.)

1. How many streets and other objects should be shown and how should they be arranged?

To obtain a sample of representative maps, cities were selected from the Index to United States Counties, Cities, and Towns of the *1995 Rand McNally Road Atlas*, the most popular road atlas in the U.S. (Rand McNally, 1995, p. 121-128). From every fifth column, the thirtieth entry was selected. If this entry was a county (in bold), then the next city or town in the column was selected. Using the selected city and town names, maps were retrieved from a popular CD-ROM database of the U.S. (*Street Atlas USA*, version 2.0, DeLorme Mapping, 1993) and displayed at magnification level 15 (one and three-sixteenths inches = 1000 feet) in a square, 5-inch diagonal display window. The area of the 5-inch diagonal square is about the same as those typically used for automotive navigation systems. This process led to a sample of 24 maps (Figure 1).

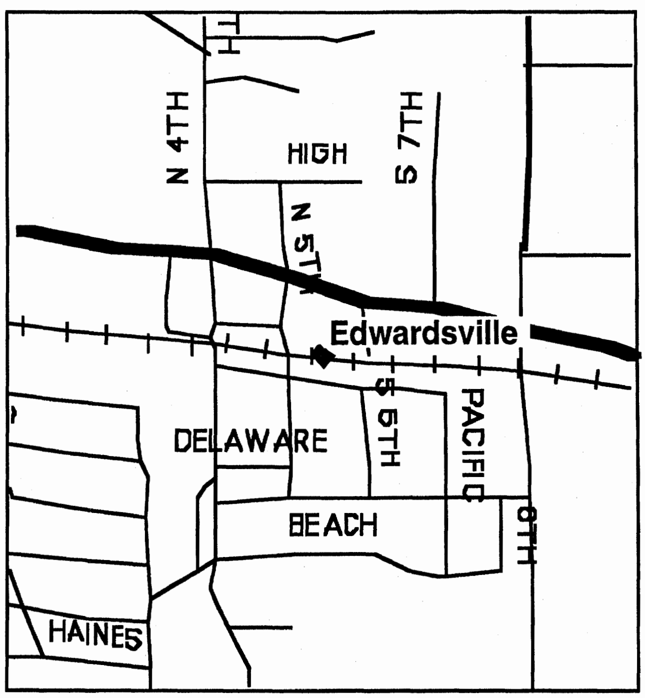


Figure 1. Section from map of Edwardsville, KS, one of the 24 maps sampled.

Table 1 summarizes some of the data obtained from those maps. The locations sampled are well dispersed throughout the U.S. This is important because road geometry varies with local geography (mountains vs. plains, ocean-side vs. inland, etc.). However, in terms of population, the locations sampled tended to be smaller towns and less urban regions in the U.S.

Table 1. Summary data from sample maps.

City / State (population)	Street levels[1]	Streets shown	Degree to which map was grid-like[2]	Railroad segments	Rivers
Yarnell AZ (1500)	2	21	2	0	1
Mccloud CA (1555)	2	34	1	5	1
Enfield CT (8454)	4	8	1	0	0
Baldwin GA (1439)	3	28	1	1	0
Chester IL (8194)	3	35	5	0	0
Holland IN (675)	3	21	5	0	0
Edwardsville KS (3979)	3	28	3	1	1
Breaux Bridge LA (6515)	3	26	3	1	1
Bondsville MA (1992)	3	23	1	2	1
Argyle MN (636)	3	19	5	2	0
Claycomo MO (1668)	3	28	1	0	1
Wadsworth NV (640)	2	31	2	1	1
Cooperston NY (2180)	3	22	3	0	2
Harkers Island NC (1759)	3	15	2	0	0
Malta OH (802)	3	22	2	0	2
Gresham OR (68235)	2	18	4	1	1
North Wales PA (3802)	2	39	5	1	0
McIntosh SD (302)	3	16	5	1	0
Hamlin TX (2791)	3	21	5	2	0
North Clarendon VT (500)	4	12	1	0	1
Glenville WV (1923)	4	29	2	0	2
Fontana WI (1635)	3	29	4	0	0
Rice Lake WI (7998)	3	24	5	5	1
Sundance WY (1139)	3	23	2	0	2
Mean	3	24	3	1	1

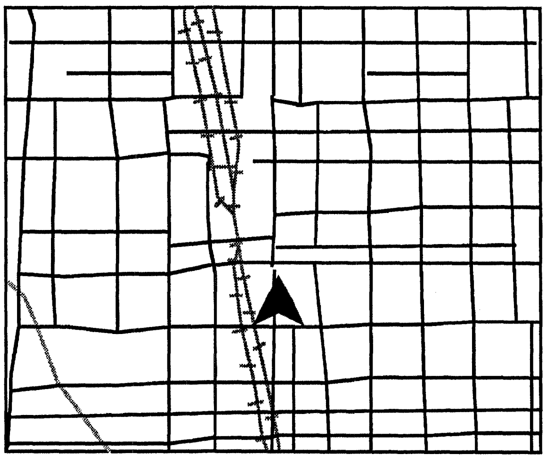
1 Street levels refers to the number of different types of streets shown (as indicated by color and line thickness on the map).

2 The judged degree to which a map was grid-like ranged from 1 (not grid-like) to 5 (very grid-like).

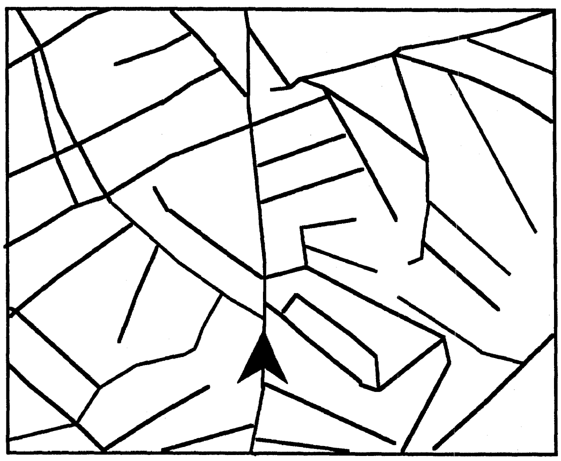
As shown in Table 1, a "typical" U.S. map might be expected to show three street levels, one railroad segment, and one river. Not shown in the table is the fact that roughly one in five maps showed a body of water other than a river, and there was only one island in the entire sample. Maps varied quite widely in their street layout and in the number of streets shown. These observations of what constituted a "typical" map are summarized below in a set of guidelines, which were used as the basis for creating maps for this project.

- The number of streets shown varied between 8 and 39 (mean = 24). To cover that range, the numbers of streets selected for investigation were 6, 12, 18, 24, and 36. Six streets is the minimum number that would allow for one street currently driven, two cross streets ahead, one cross street behind, and parallel streets to the left and right (a minimum level area map).
- Maps should include a railroad segment and a river, features that typically appeared in the sample.
- Maps should not show islands or large bodies of water. Few of the sample maps did so.
- Multiple levels of the streets (major and minor, coded by color or line thickness) may be desired. Three levels was common in the sample. However, this factor was omitted from the experiment to keep the number of factors manipulated from being excessive and to avoid complicating the design of maps. For the experiments described in this report, there was only one level of streets.
- Maps should vary in the extent to which their configurations are grid-like. Maps were typically between the two possible extremes, though there was a wide range of variation between individual maps. To explore that range, only the extremes were considered, grid and non-grid. This classification was subjective and based on a comparison with the sample of maps.

Two template maps, one grid and the other non-grid, were created using these guidelines. Each showed 36 streets. Maps showing fewer streets were derived from the templates by deleting as many streets as necessary. (This deletion was done systematically to maintain the appearance of balance on the maps.) Figure 2 displays the two template maps. Consistent with industry practice, an arrowhead icon was shown on each map to indicate the current vehicle position. As recommended by the navigation design guidelines (Green, Levison, Paelke, and Serafin, 1995), the maps were oriented heading up, the preferred orientation for route following. The icon was centered along the left-right axis, and approximately 1/3 of the distance up from the bottom (since the road ahead is more important than the road behind).



Grid template



Non-grid template

Figure 2. The two 36-street templates from which all maps in the study were derived.

2. What names should be used for the streets?

So that subjects would not have problems in recognizing names, only frequently used, western first names were selected that were not specific to a racial or ethnic group in the U.S. Name lengths were constrained to be 5 to 9 characters, as street names in that range were common in the sample of 24 maps (Figure 3). Many three-character names were numbered streets (1st, 2nd, 3rd, etc.). Omitting these, the most common lengths were seen to be 4 to 8 characters. Because the distribution is right-skewed, the range from 5 to 9 was settled on for the street names in this experiment.

A baby-naming book (Evans, 1994) was used to identify frequently occurring names. Names that have not been common until recently (e.g., Tiffany), were avoided. Appendix B contains a complete list of all first names used.

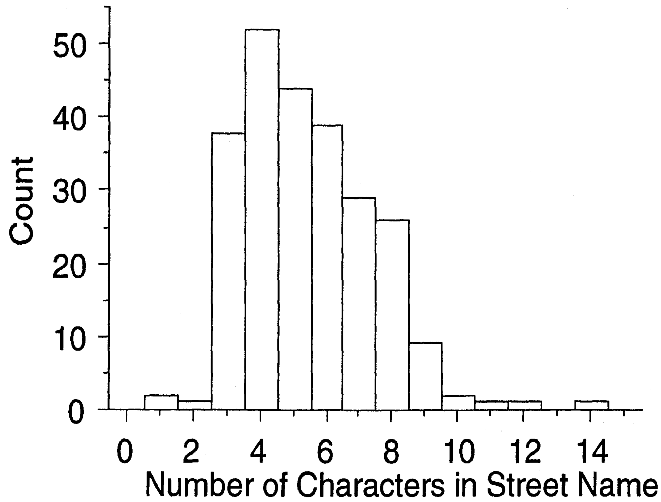


Figure 3. Distribution of street name lengths in the 24-map sample.

3. How should the street names appear on maps?

An important issue is the location of the street name label relative to a vertically running street. Figure 4 shows three possibilities, all of which occurred in this study. The same options for label orientation exist for labels of curved streets. However, it was decided that for a curved street, the label would be placed at a point where the street ran straight.

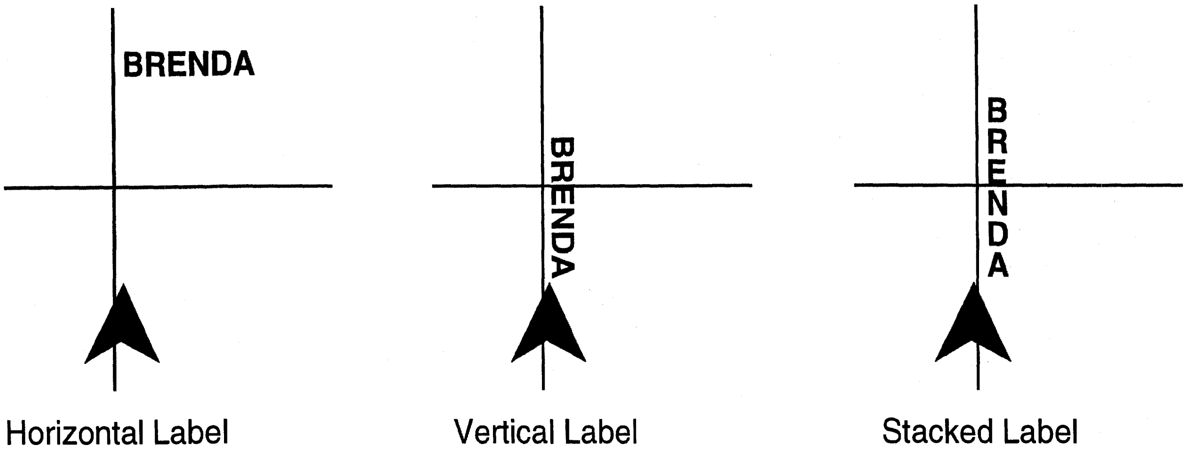


Figure 4. Street labeling options for vertical street names.

A set of rules was developed for name placement that follows common map design practice (Freeman and Ahn, 1987).

- The street label can extend beyond the length of the street itself.
- The street label was placed with white space between the label and the street beneath/above the label.
- Names were centered on non-intersected segments of a street, if possible. They were not distributed across the entire length of the street, nor were they centered based on the entire street length.
- If a street curved, the label was centered on a straight part of the street.
- When reducing the number of streets on a map, an equal number of streets were deleted on each side of the vertical center line without regard to the genders of the street names.
- Street labels were not required to remain in the same location as the map density changed (number of streets increased or decreased) or as the point size changed.
- Street labels were placed along the street line, except where other conditions were specifically required (horizontal, vertical, stacked).
- If a street curved, the beginning and end of the street label were "along" the street.
- If labels could not be placed above the line of the street, they were placed below.
- Overlapping of street names occurred only to fit the street label within the map boundaries.
- Names were shifted if one of the portions of a letter (especially a vertical stroke) fell on a street line.
- Previous rules were overridden if a horizontal name required the space.
- Stacked and vertical labels were adjusted to be read along the line of the street.
- When an non-intersected segment of street was unavailable, the label was centered along the entire street length.
- Stacked, horizontal, and vertical labels were placed on the right side of the street, unless there was no space. In this case, they were placed to the left of the street.
- Horizontal labels were strictly horizontal. No adjustments were made to the angle of the label.
- Horizontal labels were positioned with either the beginning or end of the label next to the street, depending on the space conditions.

Placement of street names also depended upon the size of the label typeface. According to the James Bond Rule, a rule of thumb for sizing characters, characters should occupy a visual angle of .007 radians with respect to their height (Smith, 1979). Accordingly, map text should be approximately 0.2 inches (5 mm) tall if viewed at 28 inches (71 cm). Larger characters may crowd the display, diminishing legibility. Hence, bigger may not always be better; in any case, two different point sizes were used on the maps. (See Appendix C for details.)

4. How should subjects signal their answers to the experimenter?

Although this question may not seem to deal directly with map construction, the method which a subject uses to respond has a strong influence on the types of street names selected for the maps. A number of options for response methods were considered, with a keypad response being the input type ultimately chosen. (See Appendix C for a detailed discussion.) Street labels were chosen to be male and female first names that were not androgynous.

TEST PLAN - Initial Legibility Experiment

Overview

The purpose of the main experiment was to determine response time and response error as a function of various map characteristics. However, since a full factorial experiment designed to consider all of the possible map display characteristics would be prohibitively large, this initial legibility experiment was conducted to identify which map characteristics should be included in the main experiment. The following questions were addressed:

1. What number of streets should be shown?
2. What point size of the labels should used?
3. What style of labels (normal print or bold print) should be used?
4. What thickness of the road lines should be used?

Test Participants

Eight licensed drivers participated in the experiment, four young (18 to 30 years, mean = 21) and four older (65 and over, mean = 67). Within each age group there were two men and two women. Participants were recruited through advertisements placed in a local newspaper and through lists of participants from previous UMTRI studies. All were paid $20 for their participation.

Corrected visual acuity ranged from 20/18 to 20/22 (mean = 20/20) for young subjects and from 20/13 to 20/40 (mean = 20/30) for older subjects. Corrective eyewear was worn by six of the eight subjects (four young and two older).

Subjects drove an average of 12,000 miles (19,312 km) per year, ranging from 5,000 to 20,000 miles (8,047 to 32,187 km), with little difference between the age and gender groups. Five subjects (four young and one older) reported using an in-vehicle navigation system during previous, unrelated UMTRI experiments. Subjects reported using a map an average of 3 to 4 times in the past six months. Young subjects reported using a computer daily, whereas older subjects had never used a computer.

Test Activities and Their Sequence

Each subject began by completing a participant consent form (Appendix D) and a biographical form (Appendix E). Each subject then had his or her vision tested. See Appendix F for the complete instructions given to each subject by the experimenter.

Two maps were shown side-by-side in front of the subject via two random access slide projectors while the subject was driving the simulator. The subject was then asked which of the two maps was most legible. The subject's response was recorded, and the next pair of maps was presented. The maps were presented as 5-inch diagonal images. Figures 5 and 6 are two examples of the maps seen by the subjects.

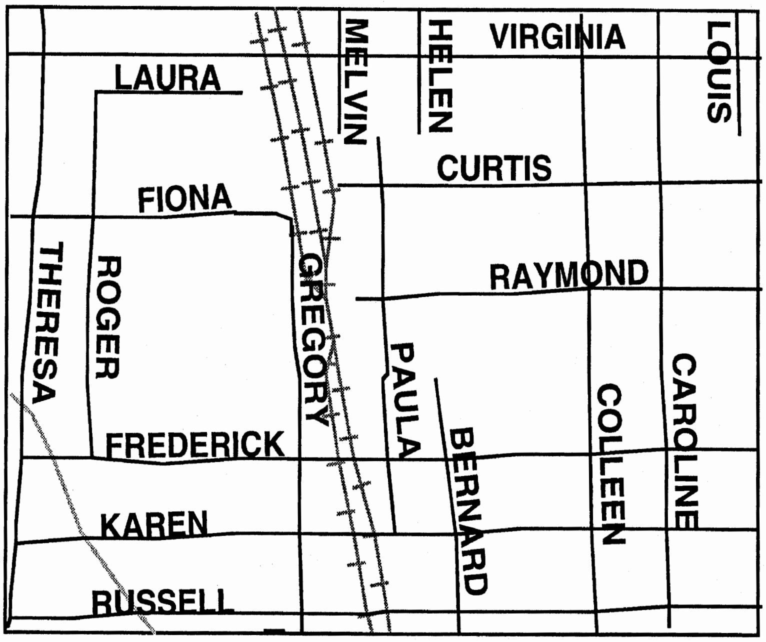


Figure 5. Grid map containing 18 streets, 12-point bold text,
and 1-point thick street lines and street name lines.

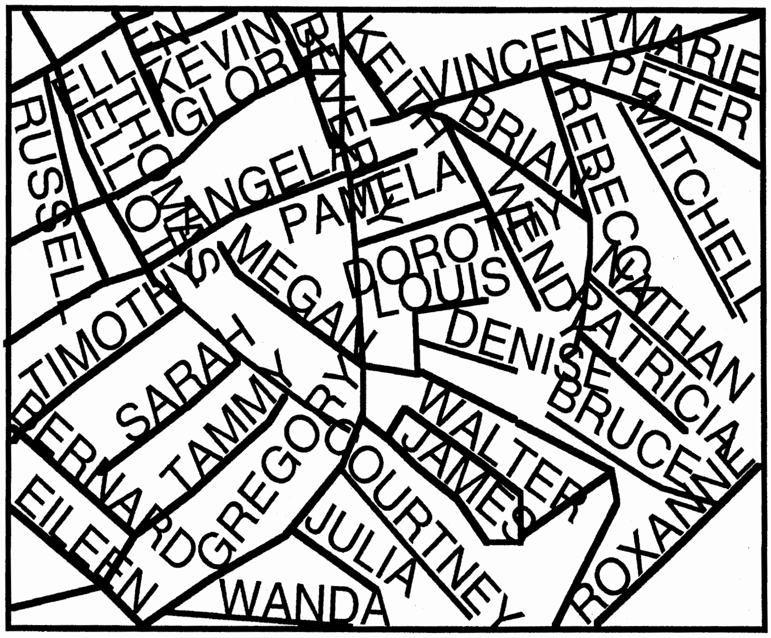


Figure 6. Non-grid map containing 36 streets, 18-point regular text,
and 2-point thick street lines and street name lines.

The two maps in each pair were either grid or non-grid, but never both. The maps shown differed in four ways, (1) the number of streets shown, (2) the size of the street labels, (3) the thickness of the street labels, and (4) the thickness of the lines used to represent the streets. Table 2 shows four factors and the levels at which they occurred.

Table 2. Factors and levels for the initial legibility experiment.

Factor	Number of Levels	Levels
Number of streets	4	18, 24, 30, 36
Size of labels	2	12-point type, 18-point type
Style of labels	2	Normal print, bold print
Road line thickness	2	1 pixel lines, 2 pixel lines

The number of possible combinations of these maps is (4)(2)(2)(2) = 32. Thus, the total number of comparisons possible is ${}_{32}C_2$, or 496. Since this number is too large for a study of reasonable length, a smaller sample of all possible comparisons was selected. It was reasoned that comparisons of maps with many streets to maps with few streets would be unnecessary, since the less cluttered maps would obviously appear more legible. Using this criterion, the number of comparisons shown was reduced to 160, a manageable number. (See Tables 3 and 4.)

Table 3. Comparisons for each combination of number of streets and point size.

	18sts, 12pt	18sts, 18pt	24sts, 12pt	24sts, 18pt	30sts, 12pt	30sts, 18pt	36sts, 12pt	36sts, 18pt
18sts, 12pt	6	16						
18sts, 18pt		6	16					
24sts, 12pt			6	16				
24sts, 18pt				6	16			
30sts, 12pt					6	16		
30sts, 18pt						6	16	
36sts, 12pt							6	16
36sts, 18pt								6
							Total:	160

Table 4. Upper left close-up showing how 6 and 16 comparisons were achieved.

		18sts,12pt				18sts,18pt				
		1n	2n	1b	2b	1n	2n	1b	2b	
18sts,12pt	1n		X	X	X	X	X	X	X	
	2n			X	X	X	X	X	X	
	1b				X	X	X	X	X	
	2b					X	X	X	X	etc.
18sts,18pt	1n						X	X	X	
	2n							X	X	
	1b								X	
	2b									

etc.

where:

n = normal text
b = bold text
1 = single-pixel wide streets
2 = double-pixel wide streets

RESULTS AND DISCUSSION - Initial Legibility Experiment

The dependent measure was the total number of times a slide would be preferred over another slide (to be referred to as the total sum). This was the sum of (1) the number of times it was actually chosen over another slide by the subject plus (2) the number of times it was assumed to have been chosen over another slide by the subject.

Since the subjects were presented with a set of grid or non-grid slides and never a pair containing both, the two data sets were analyzed separately.

Grid Maps

The main effects for number of streets, point size, street thickness, and boldness were significant. In addition, a large number of higher order interactions between the four variables were also found to be significant. (See Appendix G.) The effects of age and gender were not examined.

Unpaired t-tests were conducted to examine the difference between the levels of number of streets, point size, street thickness, and boldness. All levels of number of streets were significantly different from each other. Point sizes of 12 point and 18 point were significantly different from each other. Street thicknesses of 1 point and 2 point were not significantly different from each other. Bold font and regular font were not significantly different from each other. (See Appendix H for statistics.)

Non-grid Maps

The main effects for number of streets, point size, street thickness, and boldness were significant. In addition, a large number of higher order interactions between the four variables were also found to be significant. (See Appendix I.) The effects of age and gender were not examined.

Unpaired t-tests were conducted to examine the difference between the levels of number of streets, point size, street thickness, and boldness. All levels of number of streets were significantly different from each other. Point sizes of 12 point and 18 point were significantly different from each other. Street thicknesses of 1 point and 2 point were not significantly different from each other. Bold font and regular font were not significantly different from each other. (See Appendix J for statistics.)

Conclusions

The significance of the number of streets indicates that the number of streets shown on a map influences which of two maps a driver would prefer to view. In addition, the mean difference in the total sums between two slides increased as the difference in the number of streets presented on the two slides increased. The mean difference appears to increase linearly.

For the main experiment, slides with 30 streets can be omitted because the results of 24 streets and 36 streets can be used to interpolate the effect of 30 streets. In addition, the removal of slides with 30 streets makes the main experiment less complicated. Slides with only 6 streets shown should be used to determine the effects of empty space on a map as well as clutter.

The large amount of higher order interactions in the ANOVAs (Appendices G and I) between all four variables indicates that all levels of point size, boldness, and street thickness should be used in the main experiment. However, the main effects of boldness and street thickness were not nearly as significant as the main effects for number of streets and point size. In addition, smaller order interactions involving either boldness or street thickness were not significant as often as interactions involving number of streets and point size. Thus, it was determined that number of streets and point size should be included in the legibility experiment and boldness and street thickness should not.

TEST PLAN – Main Experiment

Overview

Given that the primary factors affecting map reading performance had been identified, a focused experimental evaluation was then feasible. In this experiment, subjects drove in a simulator and simultaneously responded to slides of electronic area maps shown on the center console. Depending upon the task being examined, drivers (1) looked for the name of the street on which they were driving, (2) looked for the name of the nth cross street (e.g., second), or (3) identified the relative location of a particular street. When drivers found the desired information, they pressed a key to record their response time.

Test Participants

Twenty licensed drivers participated in the experiment, 10 young (18-30 years, mean = 21) and 10 older (65 and over, mean = 68). Within each age group, there were five men and five women. Some participants were recruited using lists from previous UMTRI studies, but no subjects who participated in the initial legibility study were selected. All were paid $40 for their participation.

Corrected visual acuity ranged from 20/13 to 20/40 (mean = 20/22) for young subjects and from 20/13 to 20/70 (mean = 20/25) for older subjects. Corrective eyewear was worn by 11 of the 20 subjects.

Subjects drove an average of 10,850 miles (17,360 km) per year, ranging from 2,000 to 20,000 miles (3,200 to 32,000 km). Five subjects reported using an in-vehicle navigation system during previous, unrelated UMTRI experiments. Subjects reported using a map an average of 3 to 4 times in the past six months. Young subjects reported the frequent use of a computer, whereas older subjects either used a computer daily (four responses) or never used one (six responses).

Test Equipment and Materials

Data was collected in the UMTRI Driver Interface Research Simulator, a low-cost driving simulator based on a network of Macintosh computers (MacAdam, Green, and Reed, 1993; Olson and Green, 1997). The simulator consists of an A-to-B pillar mockup of a car, a projection screen, a torque motor connected to the steering wheel, a sound system (to provide engine, drive train, and wind noise), a computer system to project images of a speedometer-tachometer cluster, and other hardware. The projection screen for the road scene, offering a 30-degree field of view, was 20 feet (6.1 m) in front of the driver, effectively at optical infinity. The simulator road scene depicted a two-lane winding road with no traffic ahead, stationary oncoming cars, traffic signs, and road edge posts

Slides of map images were presented on a screen mounted on the center console (where navigation displays are often located). This location is shown in Figure 7. The display area was a 5-inch diagonal rectangle, simulating the display area of a similarly sized cathode ray tube (CRT) or liquid crystal display (LCD).

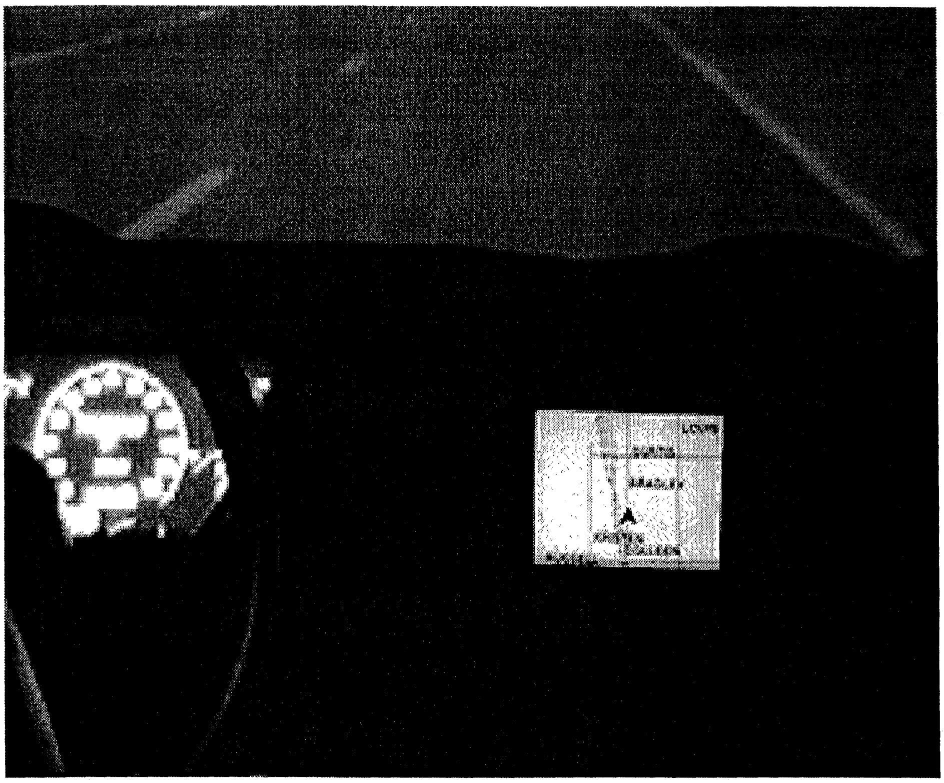
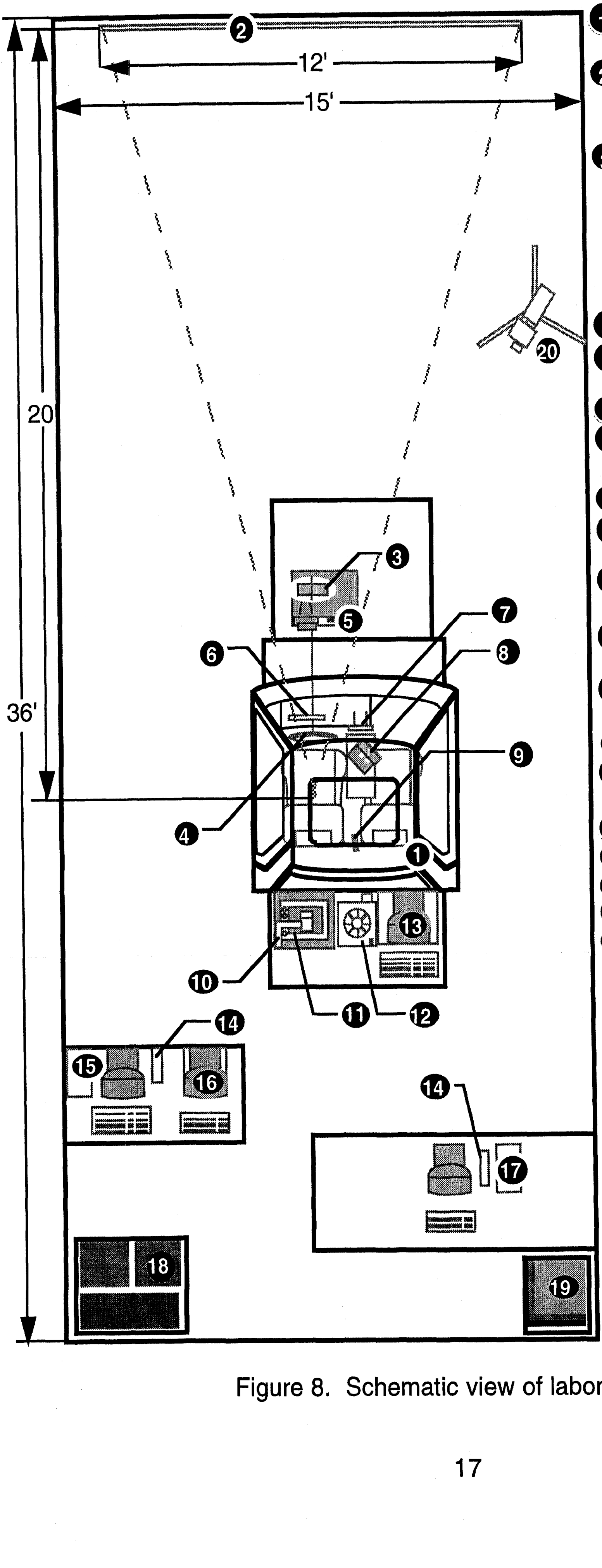


Figure 7. View of the projection screen from inside the simulator.

Slides were presented by one of three random access slide projectors (one Mast System 2, two Kodak Ektagraphic RA-960) fitted with external shutters operating under control of an IBM XT computer fitted with a custom interface/timing board. Subjects responded by pressing piano-like keys (mounted above microswitches) on a custom-made keyboard mounted between the driver and passenger seats within easy reach of the driver. All five keys were retractable to allow the experimenter to change the possible responses depending on the task. The overall arrangement of equipment at the time the experiment was conducted is shown in Figure 8.

The images shown (4 inches wide, 3 inches tall; 5-inch diagonal) were displayed on a screen located relatively high on the center console. Based on the measurements of a comfortably seated 6-foot-tall driver, the viewing distance from the eye to the center of the screen was about 30 inches (about 76 cm). The screen location was 24.5 degrees below horizontal and 34 degrees to the right of center.



1. 1985 Chrysler Laser mockup with simulated hood
2. 8'X10' projection screen with 3M hi-white encapsulated reflective sheeting
3. PMI Motion Technologies ServoDisk DC motor (model 00-01602-002 type U16M4) with Copley Controls Corp. controller (model 413) and power supply (model 645)
4. 3-spoke steering wheel
5. Sharp color LCD projection system (model XG-E850U)
6. 4"X13" plexiglas screen
7. 7.5"X9" White Foamcore Image Screen
8. Response Keyboard
9. Panasonic GP-KS152 "lipstick" Camera
10. 3M overhead projector (model 9550)
11. Sharp computer projection panel (model QA-1650)
12. Mast System 2 random-access slide projector
13. IBM PC XT
14. Bernoulli Mac Transporter 230-MB drive
15. Power Macintosh 9500/200
16. Power Macintosh 7100/80AV
17. Macintosh Quadra 840AV
18. Video recording system
19. Kenwood stereo cassette deck (model KX-48C), stereo graphics equalizer (model GE-7030), and AM-FM stereo receiver (model KRA-4080)
20. Panasonic WV-BP510 low level light camera

Figure 8. Schematic view of laboratory setup.

Test Activities and Their Sequence

Each subject began by completing a participant consent form (Appendix K) and a biographical form (Appendix E) followed by a vision test. The complete instructions given to each subject by the experimenter are located in Appendix L.

Each session was separated into two practice blocks and six test blocks. (See Table 5.) During each block of trials, the subject drove the simulator vehicle at 30 miles per hour in the right lane of a computer-generated road. Subjects were told that driving, not looking at the slides, was the priority.

Table 5. Summary of block characteristics.

Block#	Description	Point size	Trials	ITI (s)
1	Practice 1: Practice for Task 1	12 & 18	36	4.0, 5.0, 6.0
2 & 3	Task 1: What street are you on?	12	96	4.0, 5.0, 6.0
		18	96	4.0, 5.0, 6.0
4 & 5	Task 2: What is the name of the nth cross street?	12	84	4.0, 4.5, 5.0, 5.5, 6.0
		18	78	4.0, 4.5, 5.0, 5.5, 6.0
6	Practice 2: Practice for Task 3	N/A	40	4.0, 5.0, 6.0
7 & 8	Task 3: Where is the target street?	12	120	4.0, 4.5, 5.0, 5.5, 6.0, 6.5
		18	120	4.0, 4.5, 5.0, 5.5, 6.0, 6.5

The subject started each block with about 30 seconds of driving, at which point the slides started appearing on the console. A 20 ms alert tone coincided with the appearance of each slide, to which each subject responded by pressing keys with their right hand while driving with their left hand. The process repeated after an inter-trial interval (ITI) of between 4 and 6.5 seconds. (See Table 5.) For each block, ITI's were randomized and each occurred approximately equally often.

Subjects performed three tasks: Task 1 (What street are you on?), Task 2 (What is the name of the nth cross street?), and Task 3 (Where is the target street?). These tasks were chosen to span the range of map-reading activities, both in content and difficulty, as completely as possible. Task 1 was to identify the street currently being driven, Task 2 was to identify the name of a cross street ahead of the current location, and Task 3 was to locate a particular street by name and identify the location relative to the current location. See Appendix M for the rationale for selecting these tasks.

Response times (to the nearest millisecond) and errors were recorded. For error trials and for trials where the response time exceeded 25 seconds, a low-pitched 200 ms error tone sounded, followed by a 200 ms delay for recovery time.

After completing all eight blocks, each subject completed a payment form and was then paid. Each test session lasted approximately 2.5 to 3 hours.

Task Descriptions

Four factors were present throughout all tasks of the experiment: (1) the number of streets on the map (five levels: 6, 12, 18, 24, and 36), (2) the point size of the text used (two levels: 12 and 18 point), (3) the orientation of the street names (three levels: horizontal, vertical, and stacked), and (4) the street layout of each map (two levels: grid and non-grid). Not all possible combinations of point size and number of streets were examined (Table 6) because 18-point labels could not fit on a 36-street map.

Table 6. Combinations of point size and number of streets for all tasks.

Point	Number of Streets				
Size	6	12	18	24	36
12	√	√		√	√
18	√	√	√	√	

Five different pseudo-random orderings of slides were generated for each block of trials, one for each of the five subjects in each age/gender category. These variations should be sufficient to avoid confounding effects due to trial order.

The 20 subjects were divided into two groups. For each task, the first group always saw the 12-point block first (and the 18-point block second) while the second group always saw the 18-point block first (and the 12-point block second). Each group included five young and five older subjects, except for one group that accidentally included six men and four women while the other group included six women and four men (Table 7).

Table 7. Number of subjects in each category.

Point size	Young		Older	
Order	Men	Women	Men	Women
12pt → 18pt	3	2	3	2
18pt → 12pt	2	3	2	3

Practice 1: Keypad Practice (Block 1)

The purpose of the first practice task was to allow subjects to learn the association between keys and responses, to minimize additional learning of the association during the actual task. Subjects were shown a series of 36 slides such as the one in Figure 9 and identified the gender of the name by pressing a key (index finger = male, middle finger = female). Subjects were told to respond as quickly and accurately as possible.

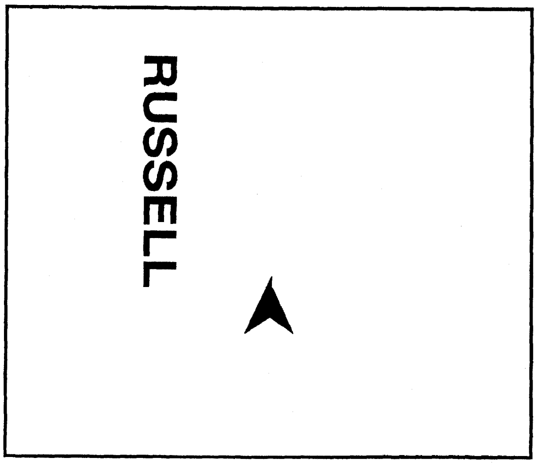


Figure 9. Practice 1 example slide.

Each combination of point size (12 and 18), orientation (horizontal, vertical, stacked), and name gender (male and female) were shown three times for a total of 36 trials.

Task 1: What street are you on? (Blocks 2 & 3)

In Task 1, subjects were shown a total of 96 slides such as the one in Figure 10. The task was to identify the name of the street currently being driven (here, "Roger"). The current street was identified by the vehicle icon (the arrowhead). When subjects found the vehicle icon and identified the name of the street, the key corresponding to the gender of the street name (left key = male, right key = female) was pressed (the left key in this example).

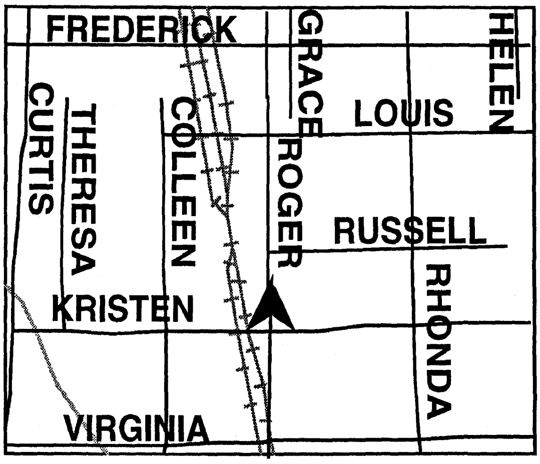


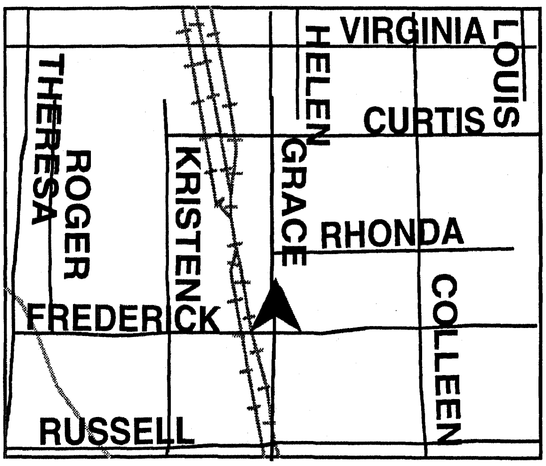
Figure 10. Task 1 example. Correct response (Roger) is "male."

Half of the subjects were shown 12 point in block 2 and 18 point in block 3, while the other half were shown 18 point in block 2 and 12 point in block 3. All combinations of number of streets (6, 12, 18, 24 for 12-point block; 6, 12, 24, 36 for 18-point block), name orientation (horizontal, vertical, and stacked), street layout (grid and non-grid), and response gender (male or female) were shown twice for a total of 96 trials.

Task 2: What is the name of the nth cross street? (Blocks 4 & 5)

Along with the "male" and " female" responses of Task 1, Task 2 added a button for "not there" used by the thumb. Subjects did not receive practice using this new button prior to testing, as the initial practice block was believed to be adequate.

In Task 2, subjects were shown 84 slides in the 12-point block and 78 slides in the 18-point block such as the one in Figure 11. The experimenter read a number from a list (ranging from 1 to 9) to the subject, after which a map appeared on the screen. The subject counted the number of cross streets ahead of the vehicle icon corresponding to the spoken number (e.g., "1" refers to the first cross street ahead of the vehicle icon, "2" refers to the second, etc.). Subjects identified the cross street as being "male," "female," or "not there" by pressing the appropriate button in a fashion similar to Task 1.



Number read:	Subject thinks:	Subject Responds:
"1"	Rhonda	Female
"2"	Curtis	Male
"3"	Virginia	Female
"4"	Not there	Not there

Figure 11. Task 2 example.

For each level of number of streets and point size, the number of trials was in multiples of six so that the factors of name orientation (three levels) and street layout (two levels) were completely balanced. Table 8 summarizes the different combinations of the number of streets on the map and the cross street named by the experimenter. These represent an attempt to balance the number of streets shown, the likelihood a street was not there, and the cross street named.

Table 8. Task 2 combinations. In the shaded regions, the correct response was "not there;" in the unshaded regions, the correct response was "male" or "female."

	12 Point				18 Point			
Cross street	Number of Streets				Number of Streets			
named	6	12	24	36	6	12	18	24
1	6	6	6	7	6	6	6	6
2		6	8	8		6	8	9
3	6				6			
4		3	4	4		3	4	3
5		3				3	3	
6			3	5			3	3
7			3					3
8								
9				6				
Total	12	18	24	30	12	18	24	24

Practice 2: Keypad Practice (Block 6)

The second practice block was used to familiarize subjects to the new responses used in Task 3. The task was to give the location of a target street relative to the vehicle icon. In this practice, the target street was indicated by a thick line. (See Figure 12.) The five possible responses were "ahead," "behind," "left," "right," or "not there." Responses of "ahead" or "behind" were used when the target street intersected the current street whereas responses of "left" or "right" were used when it did not intersect. If no thick line was present, the response was "not there."

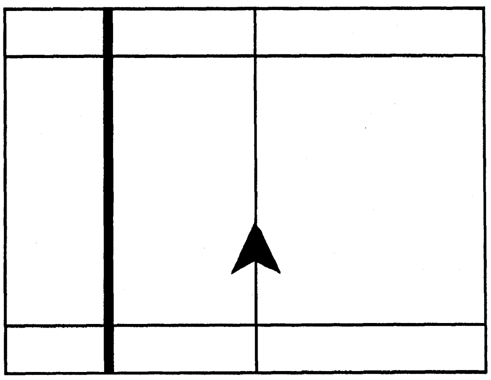
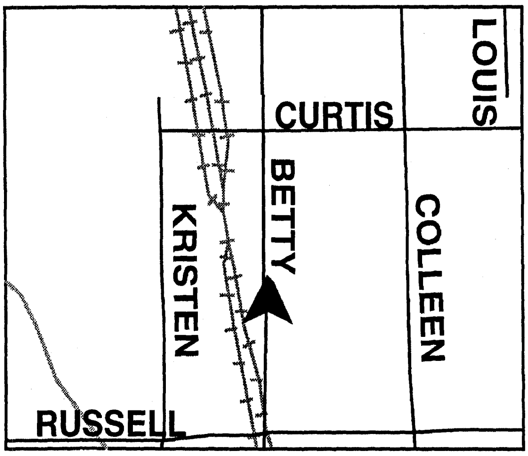


Figure 12. Practice 2 example slide. Correct response is "left."

The five street locations (ahead, behind, left, right, and not there) all had two different slides and each were shown four times for a total of 40 trials. The base template (three lines and one arrow) remained the same for all 10 different slides with only the thick line changing position.

Task 3: Where is the target street? (Blocks 7 & 8)

In Task 3, subjects were shown 120 slides within each test block such as the one in Figure 13. The experimenter read the name of a street (the "target" street) to the subject, after which a map appeared on the screen. The subject searched the map for the target street and identified its location relative to the current position on the map (the vehicle icon). The location of the target street was either ahead, behind, left, right, or not there.



Name read:	Subject answers:
Curtis	Ahead
Russell	Behind
Kristen	Left
Colleen	Right
Robert	Not There

Figure 13. Task 3 example.

In both the 12- and 18-point text blocks (blocks 7 & 8), all combinations of number of streets (6, 12, 18, 24 for 12-point block; 6, 12, 24, 36 for 18-point block), name orientation (horizontal, vertical, and stacked), street layout (grid and non-grid), and name location (ahead, behind, left, right, and not there) were shown once for a total of 120 trials.

Due to a minor error in one slide of the 18-point block, there were actually 25 "left" responses and 23 "right" responses, instead of 24 of each.

RESULTS – Main Experiment

Data Analysis

Two performance measures were independently analyzed: (1) response time and (2) error rate. An error was recorded if the subject pressed an incorrect button or if the subject failed to press any button within 25 seconds (the maximum response time) after being shown the slide. Of the 7,200 trials analyzed by ANOVA, 38 trials (about 0.5%) were omitted or replaced for one of a number of reasons (outliers, impossibly fast responses, missing slide, premature ending of the driving task, etc.). (See Table 9.) An explanation of the error trials and outliers is located in Appendix N.

Table 9. Errors and outliers for data analyzed by ANOVA.

Task	Error Trials	Outliers	Total
1 (What street are you on?)	5	11	16
2 (What is the name of the nth cross street?)	1	1	2
3 (Where is the target street?)	6	14	20
Total	12	26	38

In the ANOVA's that follow, the term significant refers to significance at the $p < 0.05$ level, though in most cases significance was at $p < 0.01$. All confidence intervals referred to in the text or shown in plots are 95% confidence intervals about the mean.

One consistent result throughout the analysis was that the length of the intertrial interval (ITI), which varied from 4.0 to 6.5 seconds, did not effect either response time or error rate for any of the tasks. Therefore, no mention is made of ITI from here on.

Task 1: On-Street Task

The data analyzed by ANOVA for this task were all combinations of number of streets (6, 12, and 24 only), point size, name orientation, and street layout. Street name gender was considered a repeated measure and was not analyzed (and in other studies has proven to not be significant). Therefore, each map design factor combination was repeated four times for a total of 144 analyzable trials per subject (2,880 total trials). As permitted by the repeated measure design, error trials and outliers were simply removed from the data set, leaving 2864 analyzable trials.

Error Rate

The overall error rate for Task 1 was 7.1%, or 202 errors out of 2864 total trials. Figure 14 shows the error rate for each subject. A between-block learning effect was evident in Task 1, as the error rate dropped from the second block (8.0%) to the third block (6.1%). This indicates that some learning occurred, even for this simple task. However, no learning effect was evident within blocks.

Factors in the repeated measures ANOVA model for response time are shown in Table 10. In this, and all subsequent analyses, between-subject factors were compared with the subject variability while within-subject factors were compared with the effect-by-subject interaction. The full error rate ANOVA for Task 1 is located in Appendix O.

Table 10. Summary error ANOVA for Task 1.

Classification	Factors	p-value
	Between subject	
Subject	Age	.072
	Gender	.61
	Age * Gender	.47
	Subject (Age, Gender)	--
	Within subject	
Map Design	Streets	<.001
	Point Size	.14
	Street Layout	<.001
	Orientation	<.001
	Streets * Point Size	.28
	Streets * Street Layout	<.001
	Streets * Orientation	<.001
	Point Size * Street Layout	<.001
	Point Size * Orientation	.014
	Street Layout* Orientation	<.001
	Streets * Street Layout * Orientation	<.001

Subject Effects

The effects of age and gender on error rate were minimal, with both factors not being significant. However, the error rate for older subjects was higher than for young subjects (means of 8.9% and 5.2%, respectively). Other differences in error rate between subject groups were small.

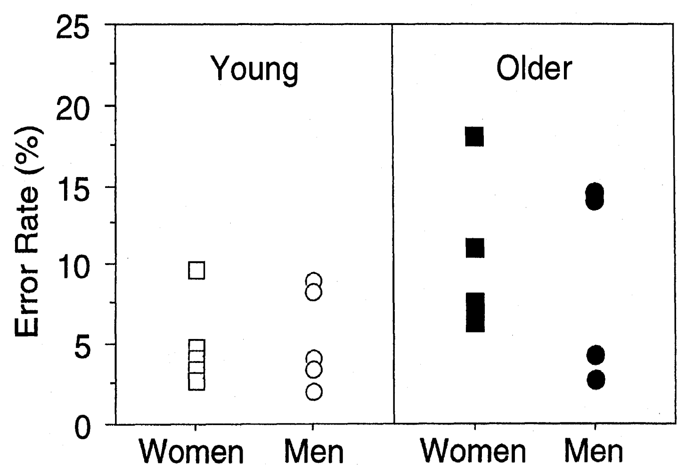


Figure 14. Task 1 error rates for all subjects by age and gender.

Map Design Effects

The number of streets on the map, the street layout, and the orientation of the street names were all significant factors on error rate; however, point size was not. Most interactions were significant, with the exception of number of streets by point size. The most notable interaction was between number of streets, street layout, and name orientation.

Name orientation significantly affected error rate. Vertically labeled streets had the lowest error rate (1.8%), followed by stacked labels (4.7%), with horizontal labels being worst (14.7%). All levels of name orientation were significantly different, according to a post-hoc test. Although point size was not a significant main effect, an interaction occurred between point size and name orientation. (See Figure 15.) For vertical and stacked street labels, the error rates for both 12 and 18 point were nearly equivalent. However, the error rate for horizontal street labels was 5% higher with 18 point than with 12 point. Stacked names gave a moderate 4.7% rate, still significantly higher than vertical according to a post-hoc test.

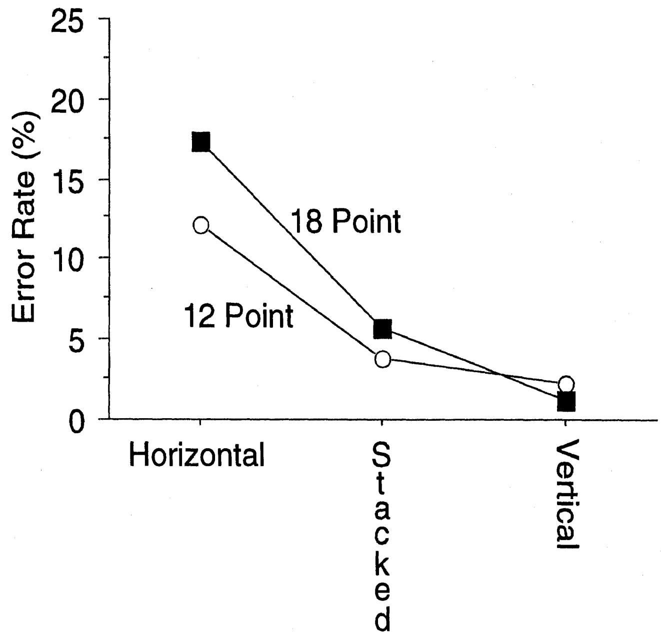


Figure 15. Point size and name orientation effects on error rates for Task 1.

For number of streets, street layout, and name orientation, the interactions had an equal or larger impact than main effects. For example, grid maps had a significantly higher error rate than non-grid maps. However, the primary difference was at 24 streets with horizontally oriented street labels, where error rate was 25% higher, a huge difference. (See Figure 16.) One other difference between grid and non-grid was at 24 streets with stacked street labels, where error rate was 6% higher on grid maps. At all other levels, grid and non-grid were effectively equal. Furthermore, the main effect of number of streets was mainly due to the high error rate that occurred for horizontally labeled streets. This did not occur for stacked and vertical labels.

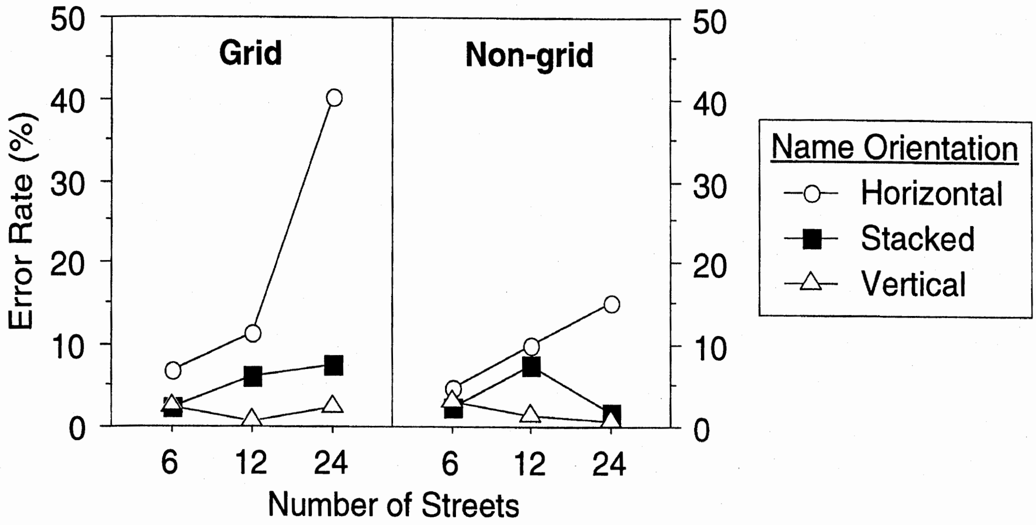


Figure 16. Interaction of number of streets, street layout, and name orientation on error rate for Task 1.

Response Time

The overall Task 1 mean response time was 1815 ms, ranging from 693 to 10280 ms. (See Figure 17.) Response times under approximately 4000 ms accounted for 95% of the data.

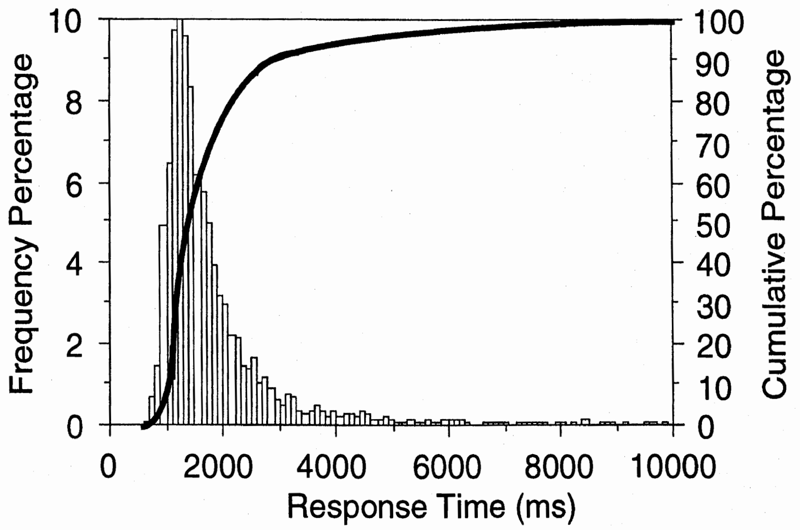


Figure 17. Task 1 overall distribution of response times.

In Task 1, response times decreased significantly from block 2 (1914 ms) to block 3 (1717 ms). Within block 2, response times decreased for approximately the first 8 trials, and remained relatively constant across the trials that followed, while in block 3, response times remained relatively constant throughout (Figure 18).

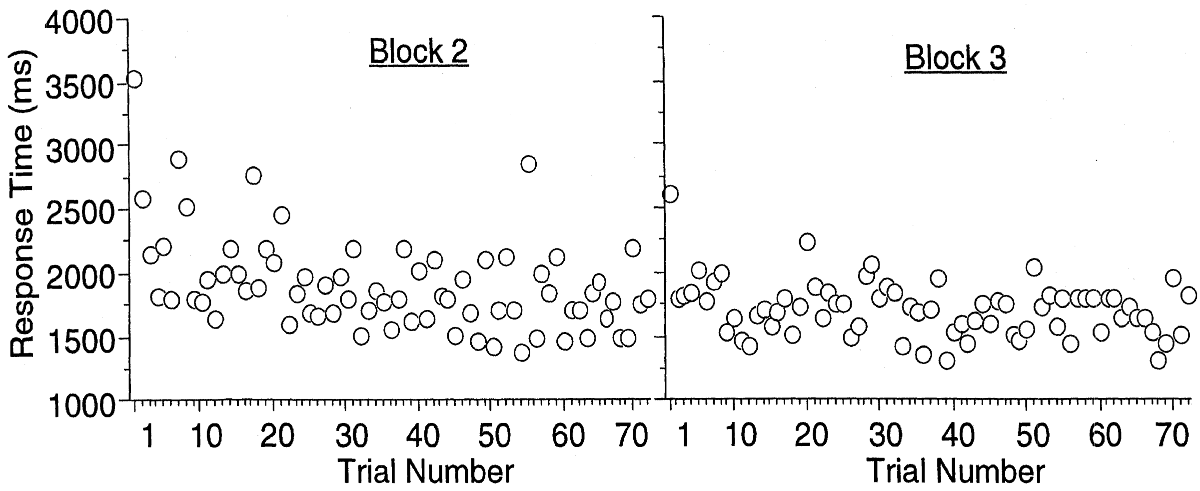


Figure 18. Task 1 mean response time by trial number for each block.

Factors in the repeated measures ANOVA model for response time are shown in Table 11. The full response-time ANOVA for Task 1 is located in Appendix P.

Table 11. Summary response-time ANOVA for Task 1.

Classification	Factors	p-value
	Between subject	
Subject	Age	.009
	Gender	.19
	Age * Gender	.063
	Subject (Age, Gender)	--
	Within subject	
Map Design	Streets	<.001
	Streets * Age	.01
	Point Size	.25
	Street Layout	.96
	Orientation	<.001
	Orientation * Age	<.001
	Streets * Point Size	.51
	Streets * Street Layout	.056
	Streets * Orientation	<.001
	Point Size * Street Layout	.026
	Point Size * Orientation	.004
	Street Layout * Orientation	.24

Subject Effects

Age was the only significant subject effect, with older subjects taking 34% longer to respond than young subjects (means of 2080 and 1552 ms, respectively). (See Figure 19.) Although the age by gender interaction was not significant, the pattern of the means (young men faster than young women, but older women faster than older men) is consistent with the literature.

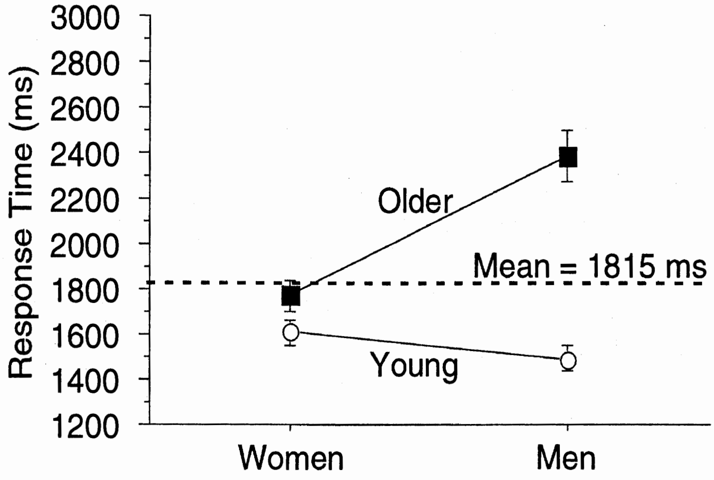


Figure 19. Age and gender effects on Task 1 response times.

Map Design Effects

The number of streets on the map and the orientation of the street names were both significant factors; however, point size and street layout were not. Also, interactions that included name orientation were statistically significant (name orientation by age, number of streets, and point size).

The interaction between name orientation and age is shown in Figure 20. The name orientations of both vertical and stacked were unaffected by age, but horizontal text was much worse for older subjects. For older subjects, horizontal text response times were 37% higher than stacked, yet only 18% higher for young subjects.

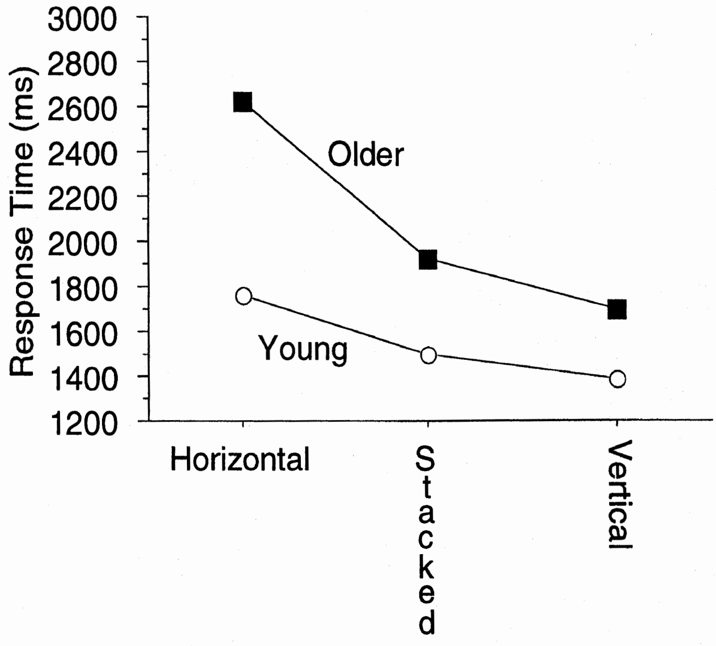


Figure 20. Interaction of name orientation and age for response time on Task 1.

Response times increased as the level of number of streets increased. However, the increase was most pronounced for the horizontal name orientation (Figure 21), where response times increased about 70 ms for each additional street.

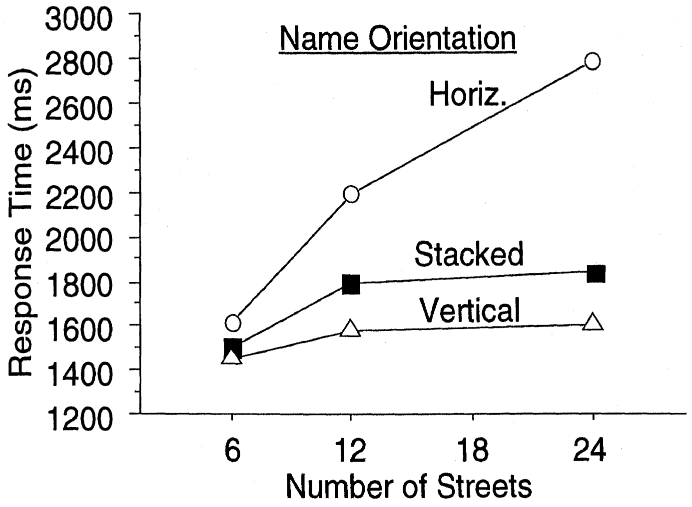


Figure 21. Interaction of name orientation and number of streets on response time.

Vertically labeled streets resulted in much faster times than the horizontal labels and slightly faster times than the stacked labels. Point size differences were only apparent for horizontally oriented text (Figure 22); the point sizes were nearly equal for stacked and vertical text (overall differences of 72 and 39 ms, respectively).

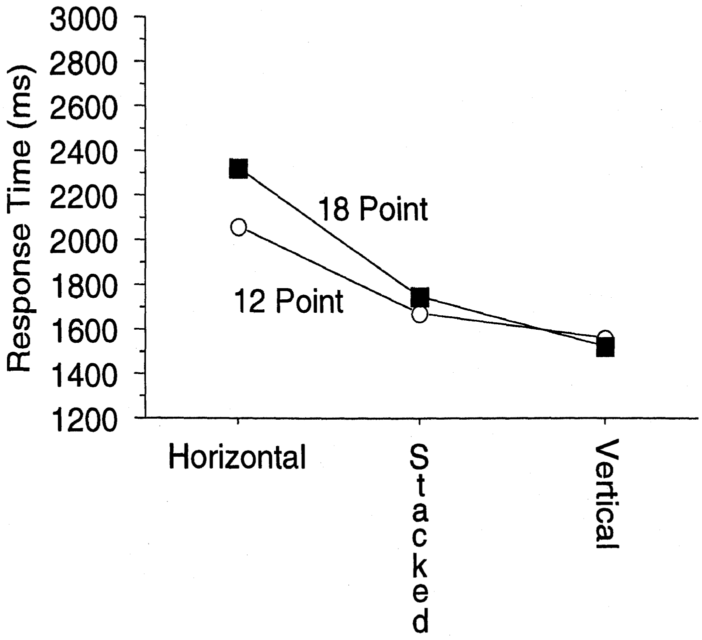


Figure 22. Interaction of point size and name orientation on response time.

Task 1 Response-Time Prediction Model

The Task 1 response-time prediction model (located below) includes five terms with three factors: age, number of streets, and name orientation. The linear effects of these factors are represented in the first three terms of the model. The next term in the model is the interaction between age and name orientation. The final term is the interaction between number of streets and name orientation. The order of effect size, from largest to smallest, was name orientation, age, and number of streets.

$$\text{Response Time (ms)} = 1334 + 264\,(A) + 31\,(S) + 378\,(Or) + 168\,(A)(Or) + 35\,(S - 14)(Or)$$

where:

$$A = \text{Age} \begin{cases} -1 & \text{for young subjects} \\ +1 & \text{for older subjects} \end{cases} \qquad Or = \text{Orientation} \begin{cases} +1 & \text{for horizontal} \\ -.28 & \text{for stacked} \\ -.72 & \text{for vertical} \end{cases}$$

S = Number of streets ($S \geq 1$)

Predicted response times given by the model are plotted against all 2,864 actual response times in Figure 23. (Note: The model generates response times in milliseconds, and the figure scale is in seconds.) The R^2 value (calculated as the percentage of variance explained by the model) was 20%, a rather low value. A higher value may have been obtained had the means been used.

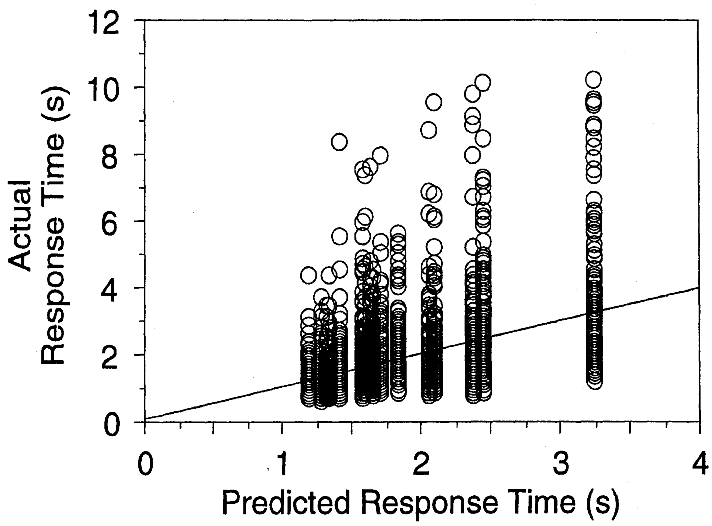


Figure 23. Predicted response time versus actual response time for Task 1.

To verify the proposed model, forward stepwise linear regression was also performed. Both models included the effects of age, number of streets, and name orientation, while excluding the effect of street layout. However, the stepwise regression also included the effect of point size, a small effect that added only 0.3% to the R^2 value. For this reason, point size was not included in the regression model. The R^2 value for this simplified model was 16% (4% less variance explained than the proposed model).

Task 2: Cross-Street Task

For Task 2, only data from the first cross street was analyzed by ANOVA, as the other data points were confounded. The data included all combinations of number of streets (6, 12, and 24 only), point size, and street layout. Name orientation was considered a repeated measure and was not analyzed. Therefore, each map design factor combination was repeated three times for a total of 36 analyzable trials per subject (720 total trials). As permitted by the repeated measure design, error trials and outliers were removed from the data set, leaving 718 total analyzable trials.

Error Rate

Factors in the repeated measures ANOVA model for error rate are shown in Table 12. The full error rate ANOVA for Task 2 is located in Appendix Q.

Table 12. Summary error ANOVA for Task 2.

Classification	Factors	p-value
	Between subject	
Subject	Age	.056
	Gender	.17
	Age * Gender	.21
	Subject (Age, Gender)	--
	Within subject	
Map Design	Streets	<.001
	Point Size	.014
	Street Layout	.71
	Streets * Point Size	.007
	Streets * Street Layout	<.001
	Point Size * Street Layout	.60
	Streets * Point Size * Street Layout	.057

Subject Effects

Age and gender did not have statistically significant effects on error rate, probably because the sample size was small. As a practical matter, age differences were large. Older subjects committed nearly three times as many errors as young subjects (14.2% and 5.3%, respectively). The error rate for women was 12.8%, and only 6.7% for men. The interaction between age and gender was not significant.

Map Design Effects

The main effects of number of streets and point size were significant, but street layout was not. All interactions between the map design factors were significant except the interaction between point size and street layout.

Error rate increased as the number of streets on the map increased. However, the increase in error rate was primarily between 12 and 24 streets (5.8% and 18.8%, respectively) and not 6 and 12 streets (4.6% and 5.8%, respectively). (See Figure 24.)

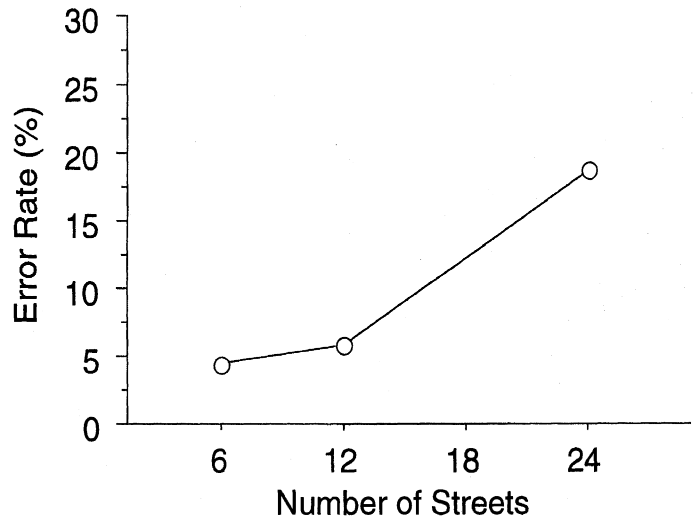


Figure 24. Number of streets effect on Task 2 error rate.

The use of 18 point produced twice as many errors as 12 point (13.1% and 6.4%, respectively), the opposite of what one might expect. Furthermore, there was a significant interaction between point size and the number of streets displayed on the map. There was no difference in error rate between 12 point and 18 point for maps with 6 streets displayed. However, there was a large difference in error rate between 12 point and 18 point for 12 and 24 streets displayed. (See Figure 25.)

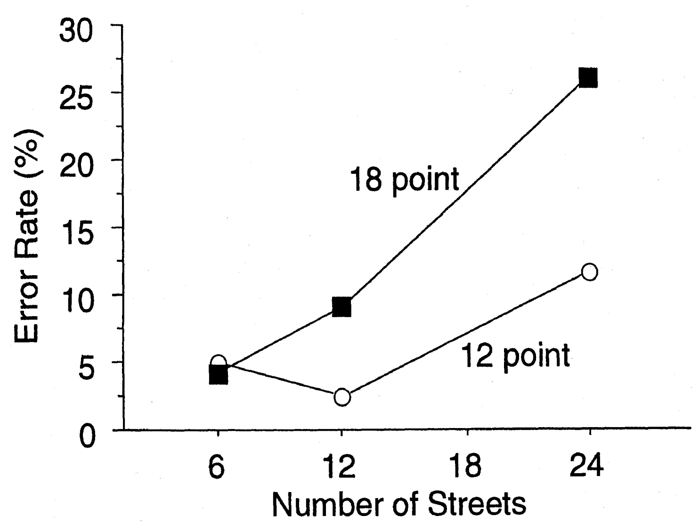


Figure 25. Interaction between number of streets and point size for Task 2 error rate.

Response Time

Factors in the repeated measures ANOVA model for response time are shown in Table 13. The full response-time ANOVA for Task 2 is located in Appendix R.

Table 13. Summary response-time ANOVA for Task 2.

Classification	Factors	p-value
	Between subject	
Subject	Age	.058
	Gender	.43
	Age * Gender	.12
	Subject (Age, Gender)	--
	Within subject	
Map Design	Streets	<.001
	Point size	.08
	Street Layout	.002
	Streets * Point Size	.018
	Streets * Street Layout	<.001
	Point Size * Street Layout	.004
	Streets * Point Size * Street Layout	.22

Subject Effects

Age and gender did not have significant effects on response time, though age was nearly significant. Older subjects took over 400 ms longer to respond than young subjects (2273 ms and 1848 ms, respectively). The difference in response time between men and women was less than 200 ms (2144 ms and 1976 ms, respectively). The interaction between age and gender was not significant.

Map Design Effects

The main effects of number of streets and street layout were significant, while point size was not. All two-way interactions between the map design factors were significant.

Response time increased as the number of streets displayed on the map increased. The increase in response time was approximately 100 ms for each additional 6 streets displayed on the map. Furthermore, while there was no significant effect of point size on response time, the effect of number of streets was more pronounced on maps with 18 point text than for maps with 12 point text. (See Figure 26.) For maps with only 6 streets, there was no difference between 12 and 18 point. However, for maps with 12 and 24 streets, 12 point led to lower average response times than 18 point.

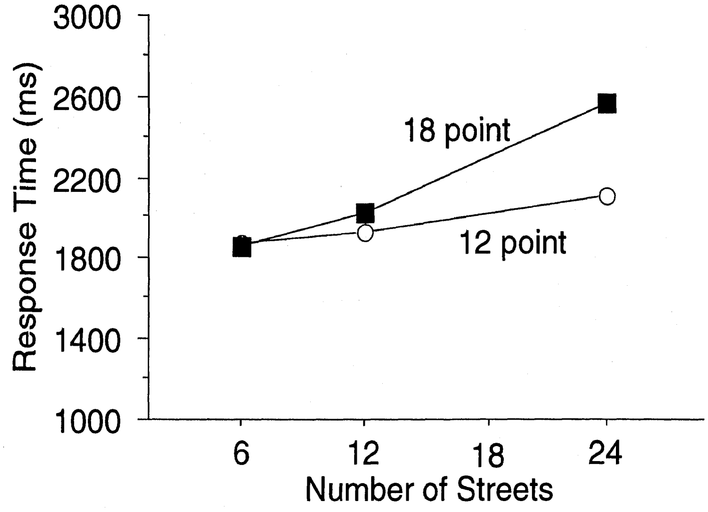


Figure 26. Interaction between number of streets and point size for Task 2 response time.

Task 3: Where Is Task

The data analyzed by ANOVA for this task were all combinations of number of streets (6, 12, and 24 only), point size, name orientation, street layout, and target street location. Therefore, there were 180 analyzable trials per subject (3,600 total trials). Error trials and outliers were replaced in the data set by the cell mean of the exact same trial in the same age/gender group (e.g. young women).

Error Rate

The mean error rate for Task 3 was 14.5%, or 523 errors out of 3600 trials. This high rate is consistent with other evidence that Task 3 is the most difficult of the tasks. A between-block learning effect was evident in Task 3, dropping from 16% in the seventh block to 13% in the eighth block. However, no learning effect was evident within blocks.

Factors in the repeated measures ANOVA model for error rate are shown in Table 14. The full ANOVA for Task 3 error rate is located in Appendix S.

Subject Effects

Age was the only subject effect found to be significant, with error rate being twice as high for older subjects (20.9%) as for young subjects (8.2%). Error rate was nearly equal for both men and women (14.2% and 14.8%, respectively), showing no significant difference. Furthermore, the age by gender interaction was not significant, with little difference between men and women in either age group (Figure 27).

Table 14. Summary error ANOVA for Task 3.

Classification	Factors	p-value
	Between subject	
Subject	Age	<.001
	Gender	.79
	Age * Gender	.83
	Subject (Age, Gender)	--
	Within subject	
Map Design	Streets	<.001
	Streets * Age	<.001
	Point Size	.13
	Street Layout	.001
	Orientation	.15
	Streets * Point Size	.37
	Streets * Street Layout	.68
	Streets * Orientation	.22
	Point Size * Street Layout	.025
	Point Size * Orientation	.036
	Street Layout * Orientation	.025
	Street Layout * Orientation * Point Size	.11
Context Effect	Location	<.001
	Location * Streets	<.001
	Location * Point Size	.056
	Location * Street Layout	<.001
	Location * Orientation	.047

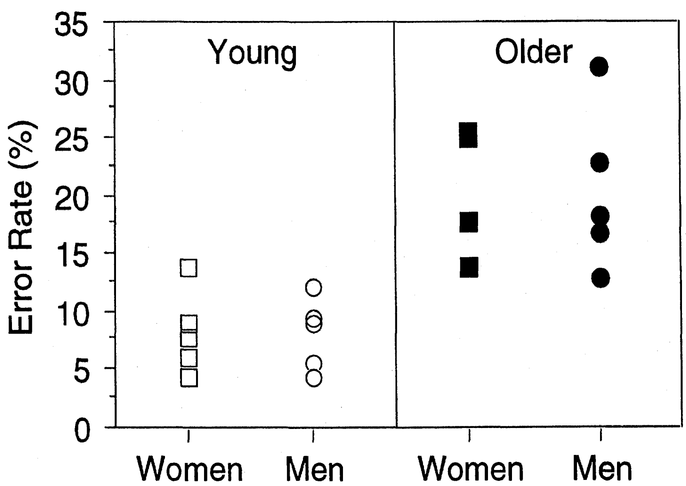


Figure 27. Age and gender effects on Task 3 error rate.

Map Design and Context Effects

The main effects of number of streets, street layout, and target street location were all significant factors on error rate; however, point size and name orientation were not. Also, all interactions between these factors were significant except those involving the number of streets on the map.

The number of streets on the map was highly predictive of error rate. Error rate increased between each successive level of number of streets, starting at 7.1% for 6 streets, 13.5% for 12 streets, and 23% for 24 streets (Figure 28). Therefore, each addition of 6 streets increased error rate by over 5% on average. Even though this effect was not totally linear, the linear model is useful for numbers of streets within the range studied. This effect was also observed across all interactions with number of streets.

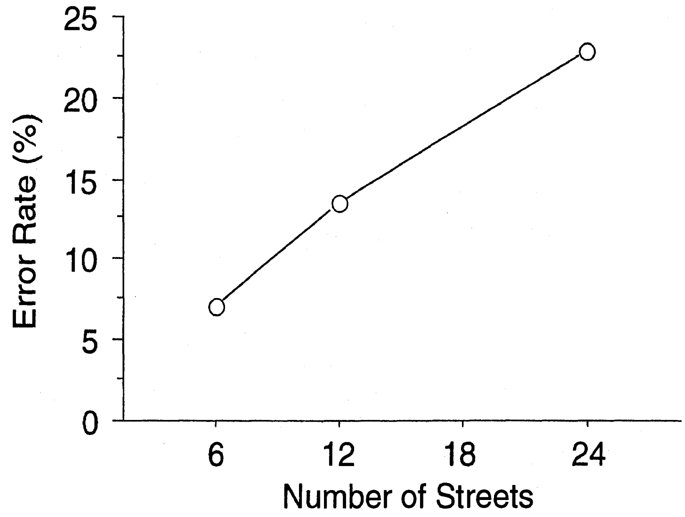


Figure 28. The effect of number of streets on Task 3 error rate.

The overall error rate for grid maps (16.5%) was significantly higher than for non-grid maps (12.6%). However, the primary difference between grid and non-grid maps was found in the interaction between street layout, name orientation, and point size, even though this interaction was not statistically significant. For non-grid maps, point size had no effect. (See Figure 29.) Also for non-grid maps, the error rate for vertically labeled streets (13.8%) was only slightly higher than for horizontal and stacked orientations (average of 11.9%). However, error rate was greatly affected by both point size and name orientation for grid maps. For 18 point text, error rate decreased almost linearly between name orientations of horizontal (24%), stacked (18.3%), and vertical (13%). For 12 point text on grid maps, the overall error rate difference was 3.3%, being lowest for the stacked orientation.

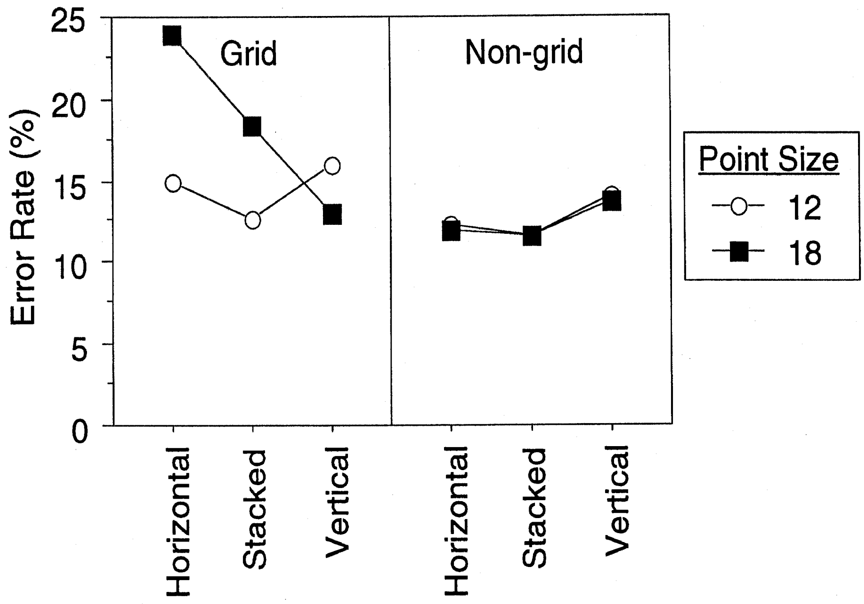


Figure 29. Interaction of street layout, name orientation, and point size on Task 3 error rate.

Response Time

The overall Task 3 mean response time was 4294 ms, ranging from 419 to 20,569 ms. (See Figure 30.) Response times under approximately 10,000 ms accounted for 95 % of the data.

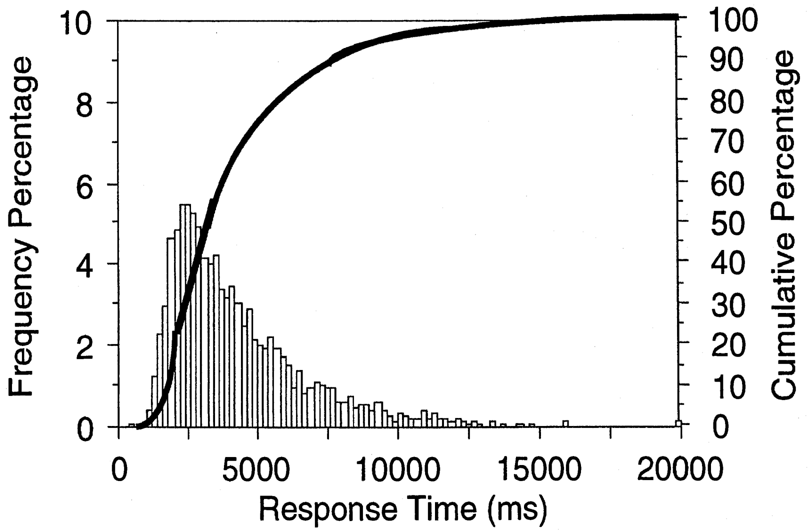


Figure 30. Task 3 overall distribution of response times.

A between-block learning effect was evident, where the mean response time decreased between the seventh block (4404 ms) and the eighth block (4183 ms), a 5% decrease overall. However, there was no discernable learning effect within each block (Figure 31).

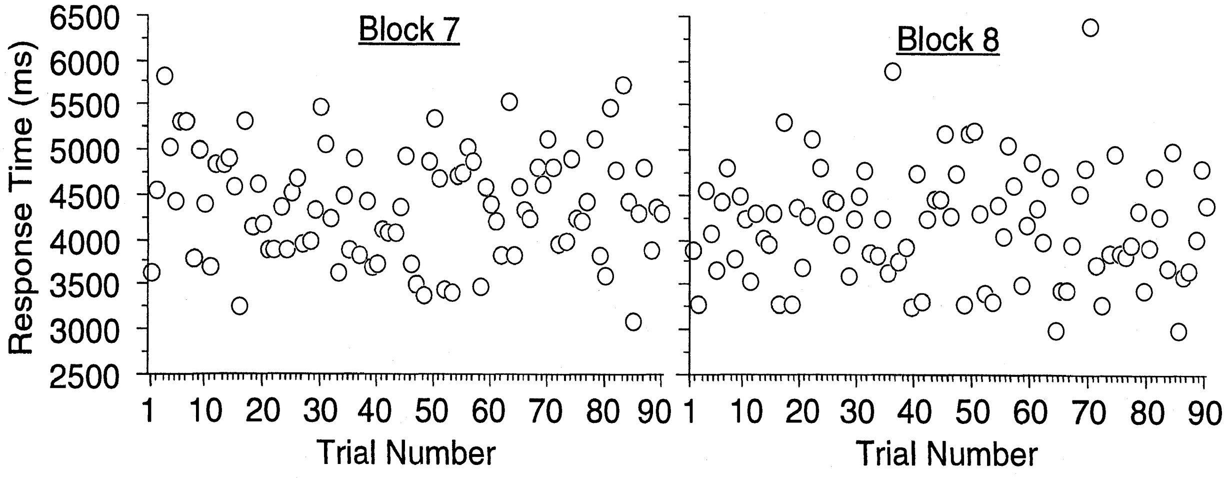


Figure 31. Task 3 mean response time by trial number for each block.

Factors in the repeated measures ANOVA model for response time are shown in Table 15. The full ANOVA for Task 3 response time is located in Appendix T.

Table 15. Summary response-time ANOVA for Task 3.

Classification	Factors	p-value
	Between subject	
Subject	Age	.007
	Gender	.074
	Age * Gender	.25
	Subject (Age, Gender)	--
	Within subject	
Map Design	Streets	<.001
	Point size	<.001
	Point Size * Age	.003
	Street Layout	<.001
	Orientation	.28
	Streets * Point Size	.018
	Streets * Street Layout	.006
	Streets * Orientation	.89
	Point Size * Street Layout	.68
	Point Size * Orientation	.067
	Street Layout * Orientation	.022
Context Effect	Location	<.001
	Location * Streets	<.001
	Location * Point Size	.040
	Location * Street Layout	<.001
	Location * Orientation	.004

Subject Effects

The effect of age was significant while the effect of gender was not. Older subjects (4940 ms) took almost 35.5% longer than young subjects (3647 ms). The average response time for men (4691 ms) was 20.4% longer than for women (3896 ms). (See Figure 32.) The interaction between age and gender was not significant.

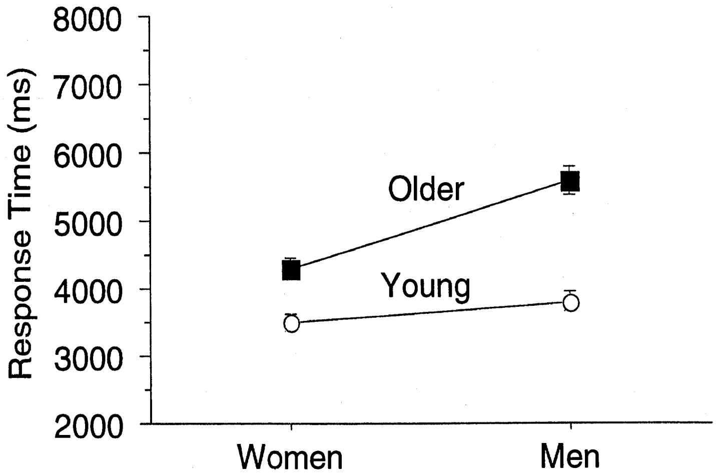


Figure 32. Age and gender effects on Task 3 response time.

Map Design and Context Effects

The number of streets on the map, street layout, point size, and target street location had significant effects on response time, but street name orientation did not. Nearly all interactions were significant.

Clearly, there is a qualitative difference between searching for a street name which happens to be on the map and searching for a name which is not shown. In the latter, every name on the map must in principle be searched, whereas in the former, searching ends when the name is first found (self-terminating search). Thus, different response times might be expected depending on where (and whether) the target name appears on the map. The target street location interacted with the number of streets on the map. Response times were generally unaffected by target street location when only 6 streets were shown on the map. (See Figure 33.) However, as the number of streets on the map increased, responses of "not there" had significantly higher response times than the other target street locations. This effect was more pronounced for higher numbers of streets. Also, for maps with 24 streets, response times for "right" also differed from the other street locations. The overall effect of the number of streets on the map can also be seen in Figure 33. If responses of "not there" are ignored, the overall mean for each level of number of streets yields an effect of approximately 116 ms per street between 6 and 24 streets. This is a much lower value than that reported by Stiltz and Yitzhaky (1979) as described in the introduction to this report (0.4 seconds per street).

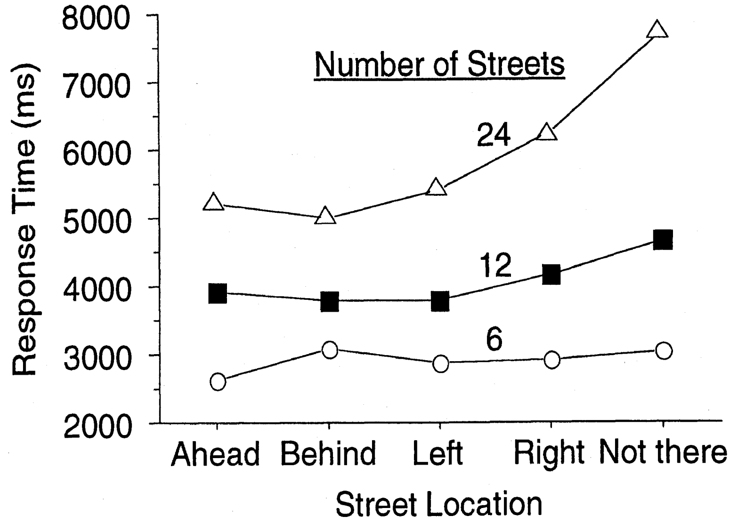


Figure 33. Interaction of target street location and number of streets on Task 3 response times.

The main effect of name orientation was not significant. However, the effect of street layout and the interaction between name orientation and street layout were both significant. For all name orientations, mean response times were higher on grid maps; 1.7% higher for horizontally labeled streets, 11% for stacked, and 4.7% for vertical. (See Figure 34.) For non-grid maps, stacked and vertically oriented street names had slightly lower mean response times than horizontal names. For grid maps, horizontal and vertically oriented street names had lower response times than stacked names.

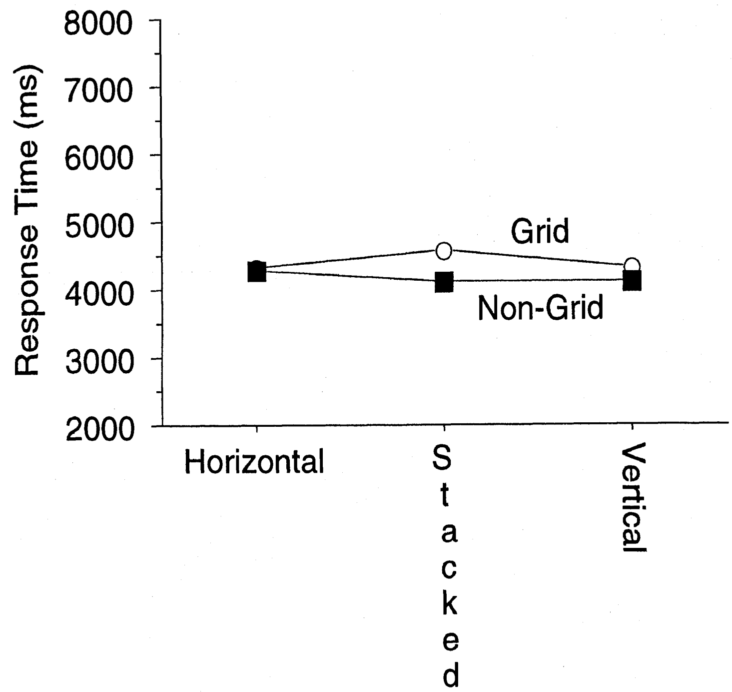


Figure 34. Street layout and name orientation effects on Task 3 response times.

Point size significantly affected response times for Task 3. The overall mean response time for 12 point (4484 ms) was 9.3% higher than for 18 point (4104 ms), the opposite of the result for the other tasks. The interaction between point size and the number of streets on the map (Figure 35) shows that the point size effect became greater as the number of streets increased.

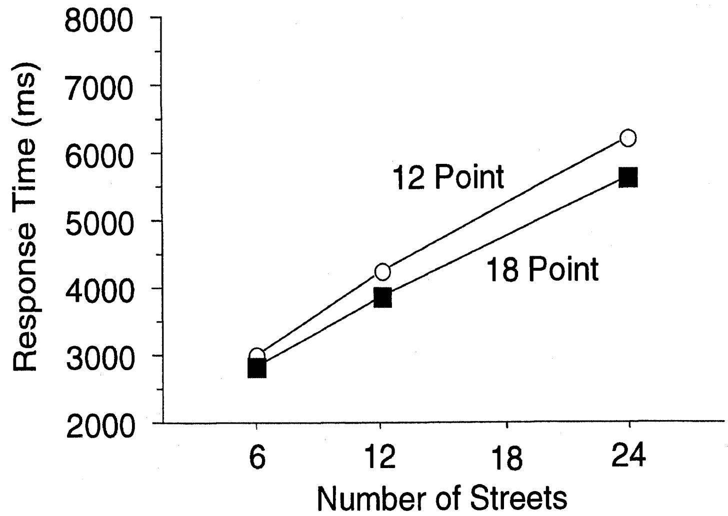


Figure 35. Effects of point size and number of streets on response time for Task 3.

Task 3 Response-Time Prediction Model

The response-time prediction model for Task 3 (located below) includes five terms with four factors: age, number of streets, point size, and search result. The linear effects of these factors (not including search result) are represented in the first three terms of the model. The next term in the model is the interaction between age, number of streets, and point size. The final term in the model represents the search result, where a response-time penalty was assessed when the target was not found. Effect size order, from largest to smallest, was number of streets, age, and point size.

$$\text{Response Time (ms)} = [\,2850 + 572\,(A) + 116\,(S) - 44\,(P) + 5\,(A + 0.5)(S - 9)(15 - P)\,] * SR$$

where:

$$A = \text{Age} \begin{cases} -1 \text{ for young subjects} \\ +1 \text{ for older subjects} \end{cases}$$

S = Number of streets ($S \geq 1$) P = Label point size ($12 \leq P \leq 18$)

$$SR = \text{Search result} \begin{cases} 1.0 \text{ if found} \\ \left(\dfrac{10 + S}{12 + 0.5 * (S)}\right) \text{ if not found} \end{cases}$$

Predicted response times given by the model are plotted against all 3,600 actual response times in Figure 36. (Note: The model generates response times in milliseconds, and the figure scale is in seconds.) The R^2 value (calculated as the percentage of variance explained by the model) was 32%, quite good considering the raw data was used.

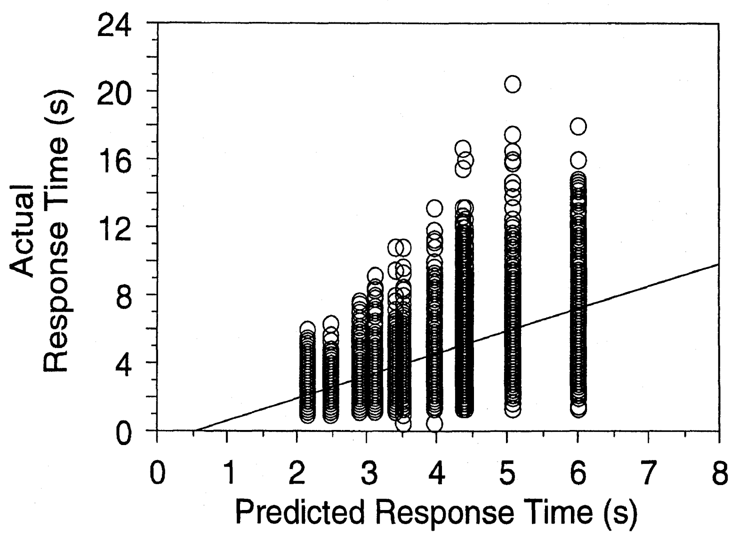


Figure 36. Predicted response time vs. actual response time for Task 3.

Forward stepwise linear regression was also performed to verify the accuracy of the proposed model. Both models included the effects of age, number of streets, and point size, while excluding the effect of name orientation. However, the stepwise regression also included the effects of street layout and target street location. Since the effects of these factors were both small, and because these factors cannot be manipulated by map designers, neither variable was included in the regression model.

EXPERIMENT COMPARISON

Of the four experiments that were performed for this project, the first two were simulator studies. These two simulator studies had many fundamental similarities that allowed for the comparison of like trials. The similar trials between the two experiments had the following characteristics:

- Grid maps
- 12-point text
- Vertically oriented text
- 12 and 24 labeled streets

The current study (experiment 1) was compared to the study by Brooks and Green (1998) (experiment 2). The similar trials between these two studies were compared for Task 1 (What street are you on?) and Task 3 (Where is the target street?). In Task 1, young subjects were remarkably similar between the two experiments (Figure 37), with mean response times differing by about 2%. Response times for older subjects in experiment 2 were 9 to 17% higher than in experiment 1. The small effect of number of streets (4 to 10 ms per additional labeled street) was generally maintained, except for older subjects in experiment 2, where the number of streets were effectively equivalent. The overall correlation between the two experiments of r = 0.97 (n = 4) was very high, but for only a limited number of data points.

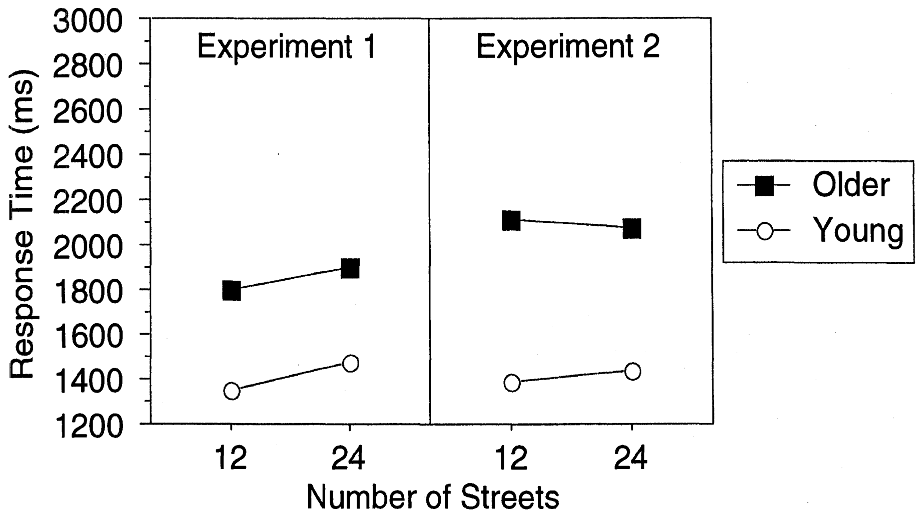


Figure 37. Experiment comparison of number of streets by age for Task 1.

The two studies were also compared for Task 3 (Where is the target street?) with target street locations of "ahead," "behind," and "left/right." Locations of "not there" were not compared. Overall, the mean response times of the two experiments were very close across age and number of streets. (See Figure 38.) The number of labeled streets effect was maintained across experiments, being lower for young subjects (146 ms per additional labeled street) than for older subjects (209 ms per additional labeled street). However, mean response times across each of the target street locations (ahead, behind, left/right) differed more greatly between the two experiments, thus lowering the correlation. The overall correlation between the two experiments was r = 0.85 (n = 12).

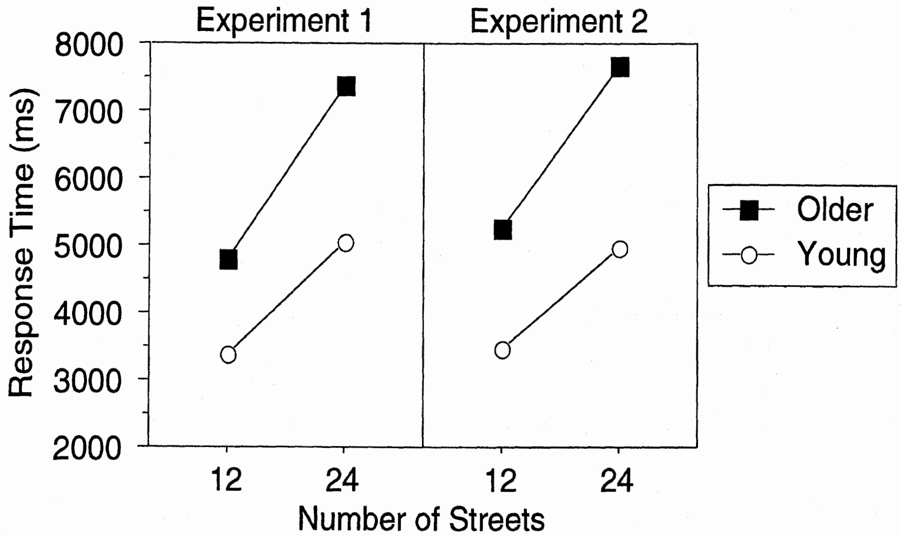


Figure 38. Experiment comparison of number of streets by age for Task 3.

CONCLUSIONS – Main Experiment

This section sets out to answer the questions which were given in the introduction. Primarily, these questions deal with the effects of various experimental conditions on the mean response time and error rate with which the subjects were able to complete the three tasks.

How did the map-reading task affect response times and errors?

Response times and errors were dependent upon the task performed. Task 1 (What street are you on?) had a relatively low difficulty level, generally requiring only one glance to the map. Response times ranged from about 1 to 4 seconds, with a mean of 1.82 seconds, and an error rate of 7.1%. Task 2 (What is the name of the nth cross street?) was more difficult, even though only the data for the first cross street was analyzed. Response times ranged from 1 to 8 seconds, with a mean of 2 seconds, and an error rate of 9.8%. Task 3 (Where is the target street?) was also very difficult, where the response times and error rate were primarily dependant on the number of streets to search. Response times ranged from about 2 to 10 seconds, with a mean of 4.29 seconds, and an error rate of 14.5%.

How did subject age and gender affect map reading time and errors?

Age had a significant effect on response time for Task 1 (On-street) and Task 3 (Where is?), where older subjects (ages 65+) took about 35% longer to respond than young subjects (ages 18-30). (See Table 16.) Error rate was also significantly higher for older subjects on Task 3. Although some of the effects were not significant, response times and error rates were always higher for older subjects. For Task 1 response times, the number of streets and street label orientation affected older subjects more than young subjects. For Task 3 error rate, the number of streets and target street location affected older subjects more than young subjects. For Task 3 response times, text point size and target street location affected older subjects more than young subjects.

Table 16. Ratios of older to young for response time and error rate.

	Ratio of Older to Young	
	Response Time	Error Rate
Task 1: On-Street	1.34 : 1	1.71 : 1 *
Task 2: Cross Street	1.23 : 1 *	2.68 : 1 *
Task 3: Where Is?	1.35 : 1	2.54 : 1

* not a significant effect

Across all of the tasks, there were no significant differences between men and women for either response time or error rate.

How many streets should be displayed?

Response times and errors significantly increased as the number of labeled streets on the map increased, with the effect size dependent on the task. In Task 1 (On-street), response time increased approximately 31 ms per labeled street. However, for the more difficult search task (Task 3), each additional labeled street added about 167 ms. Furthermore, response time and error rate typically increased above 12 labeled streets. Additional street labels either added more clutter to a map (as in all tasks) or required more items to be searched (as in Task 3). Therefore, to allow for accurate map reading, the number of labeled streets should be held to 12 or fewer.

What size text should be used?

The most pronounced differences between the two levels of point size (12 and 18 point) were observed in Task 2 (Cross street). In this task, both error rate and response time were lower for 12-point text when the map contained 12 or more labeled streets. However, on maps with 6 labeled streets, there was no difference between 12- and 18-point text. Therefore, 18-point text should be used with very few labeled streets on the map (6 or fewer), and 12-point text should be used with higher numbers of labeled streets. Data on the merits of text sizes between 12 and 18 point were not examined, but could be likely candidates.

What street name orientation should be used?

The street name label orientation had a significant effect on response time for Task 1 and error rate for Tasks 1 and 3. Overall, response time and error rate were highest for horizontal street labels and lowest for vertical street labels. Also, stacked street labels had slightly higher response times and error rates than vertical street labels.

The interaction between number of streets and name orientation in Task 1 indicated that street label orientation on maps with only 6 streets did not have an effect on response time or error rate. However, for higher numbers of streets, the street label orientation becomes an increasingly important factor. When more than 6 streets were labeled, horizontal street labels always had the highest response time and error rate, while vertical street labels had consistently lower response time and error rate. Thus, streets should be labeled vertically whenever possible. Also, horizontal labels should never be used on vertical streets, especially when maps contain more than 6 streets.

How did street layout affect response time and error rate?

The street layout had significant effects on error rate in Tasks 1 and 3 and response time in Tasks 2 and 3. Error rate was about 4% higher on grid maps for Tasks 1 and 3. The effects of response time were unclear, with non-grid maps having a higher average response time in Task 2 and grid maps having a higher response time in Task 3. However, the street layout can only be determined by the street layout in any given environment and cannot be controlled by the map designer.

How can response time be predicted?

The response time regression equations for Tasks 1 and 3 are presented in Table 17. These equations can be used to predict driver response times when attempting to identify the street being driven (Task 1) or the location of a particular street on a map (Task 3).

Table 17. Response time regression equations for Task 1 and Task 3.

Response Time (ms)		Prediction Equation
Task 1 (On-street)	=	1334 + 264 (A) + 31 (S) + 378 (Or) + 168 (A)(Or) + 35 (S - 14)(Or)
Task 3 (Where is?)	=	[2850 + 572 (A) + 116 (S) - 44 (P) + 5 (A + 0.5)(S - 9)(15 - P)] * SR

where:

$$A = \text{Age} \begin{cases} -1 \text{ for young subjects} \\ +1 \text{ for older subjects} \end{cases}$$

$$Or = \text{Orientation} \begin{cases} +1 \text{ for horizontal} \\ -.28 \text{ for stacked} \\ -.72 \text{ for vertical} \end{cases}$$

S = Number of streets ($S \geq 1$)

P = Label point size ($12 \leq P \leq 18$)

$$SR = \text{Search Result} \begin{cases} 1.0 \text{ if found} \\ \left(\dfrac{\#\text{names}}{3 + 0.5 * (\#\text{names})} \right) \text{ if not found} \end{cases}$$

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APPENDIX A – Experimental Maps

In the following pages are presented half of the 96 maps which were used for this study. Each map is classified according to five criteria:

1. Number of streets. This can be 6, 12, 18, 24, or 36, depending on the size of the letters –12-point size occurs only with 6, 12, 24, or 36 streets; 18-point occurs only with 6, 12, 18, or 24 streets.

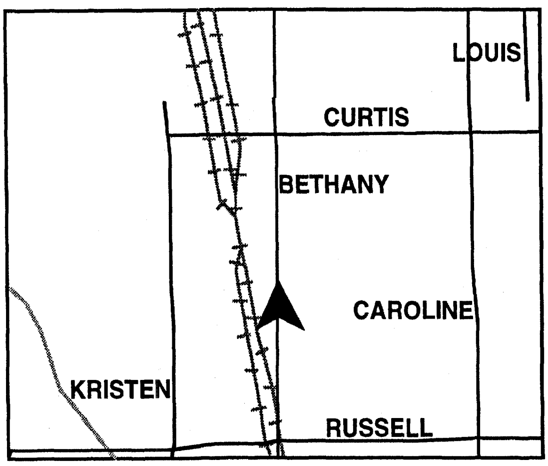
2. Name orientation. This describes the labeling of streets which run vertically. The labels may be horizontal, vertical, or stacked. See the maps for examples of each.

3. Street layout. This tells whether the streets are organized on the map in a grid or a non-grid fashion.

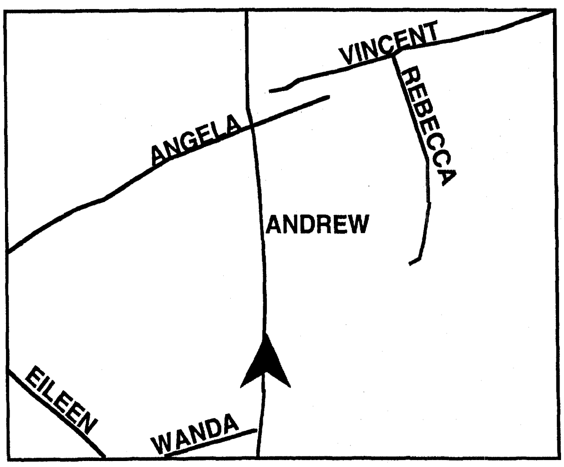
4. Point size. This describes the size of the letters in street names as they would appear to the subjects during the study. Point size can be either 12 point or 18 point.

5. Response gender. This tells the gender of the name of the current street (i.e., the street where the arrow is positioned).

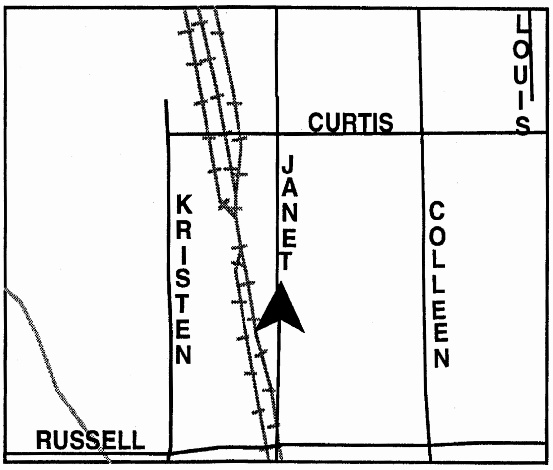
For each possible combination of the first four criteria, only one of the two maps is shown below. The other (not shown) is identical except that some or all of the street names are changed.



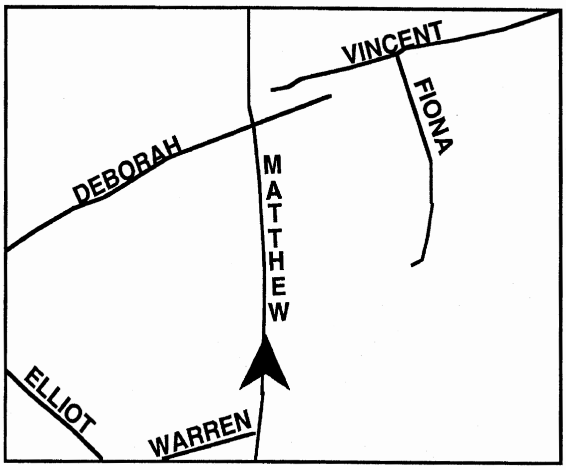
Map 1. 6 Streets, Horizontal labels, Grid, 12 Point, Female name



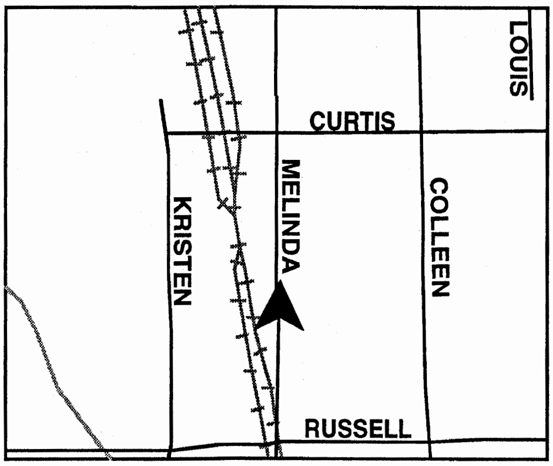
Map 2. 6 Streets, Horizontal labels, Non-grid, 12 Point, Male name



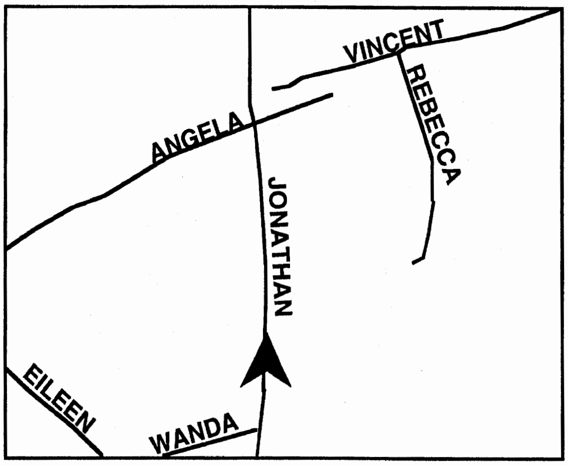
Map 3. 6 Streets, Stacked labels, Grid, 12 Point, Female name



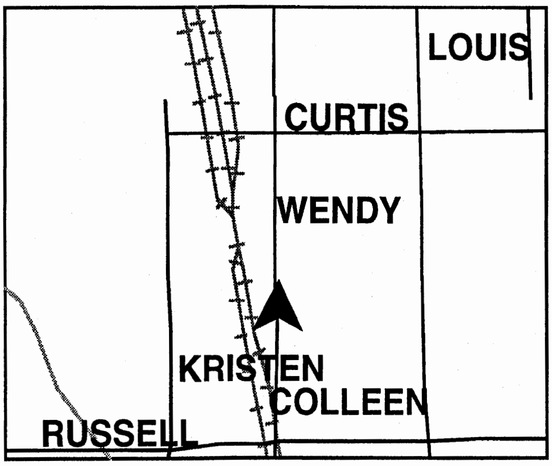
Map 4. 6 Streets, Stacked labels, Non-grid, 12 Point, Male name



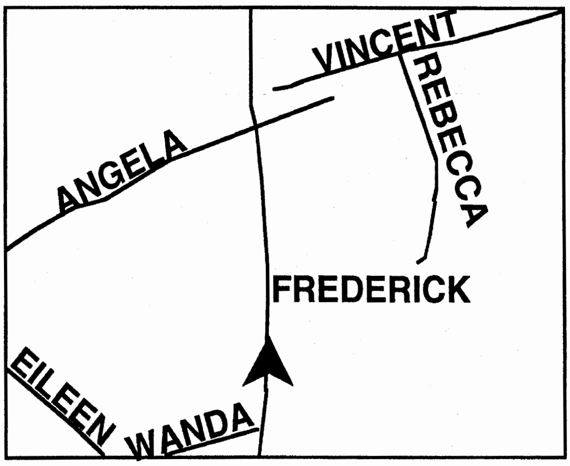
Map 5. 6 Streets, Vertical labels, Grid, 12 Point, Female name



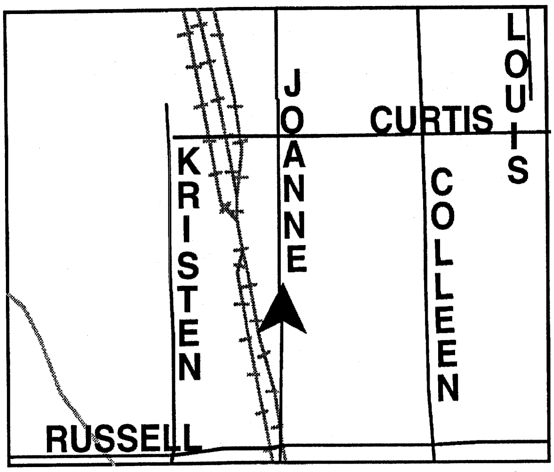
Map 6. 6 Streets, Vertical labels, Non-grid, 12 Point, Male name



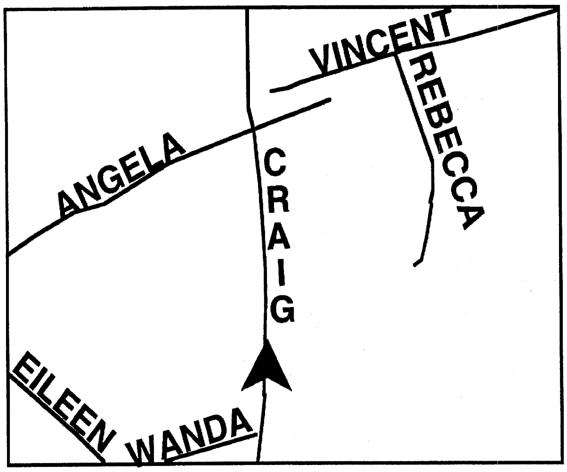
Map 7. 6 Streets, Horizontal labels, Grid, 18 Point, Female name



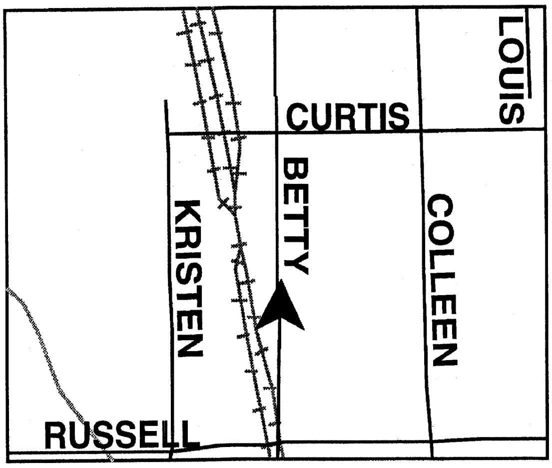
Map 8. 6 Streets, Horizontal labels, Non-grid, 18 Point, Male name



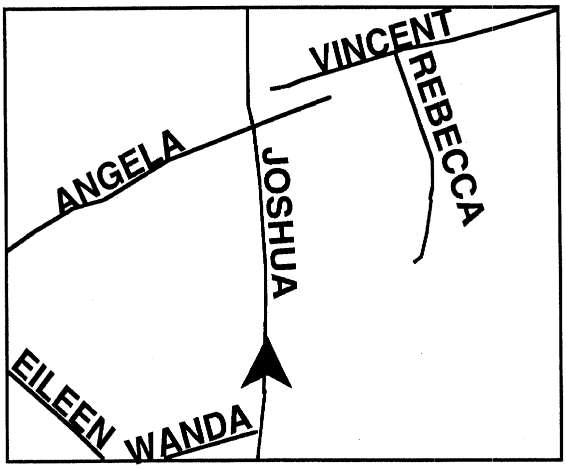
Map 9. 6 Streets, Stacked labels, Grid, 18 Point, Female name



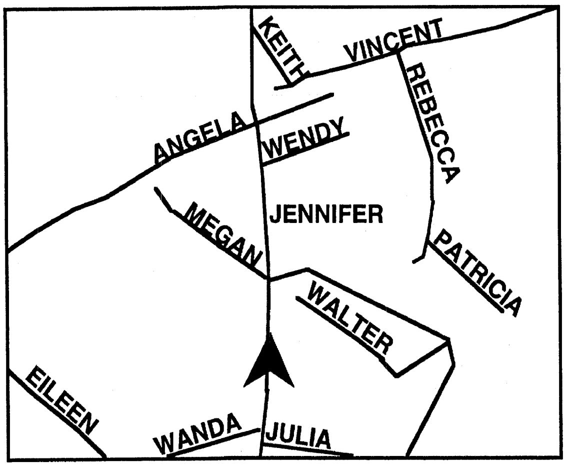
Map 10. 6 Streets, Stacked labels, Non-grid, 18 Point, Male name



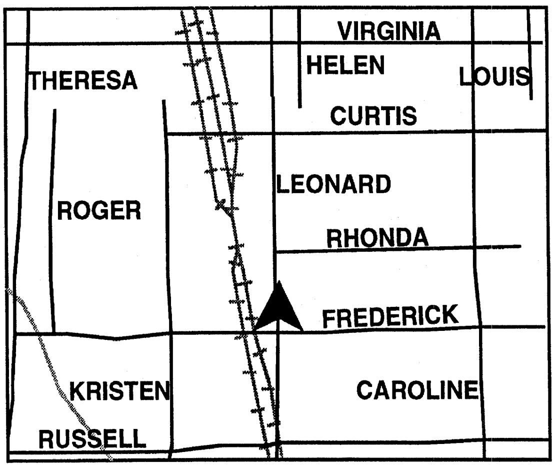
Map 11. 6 Streets, Vertical labels, Grid, 18 Point, Female name



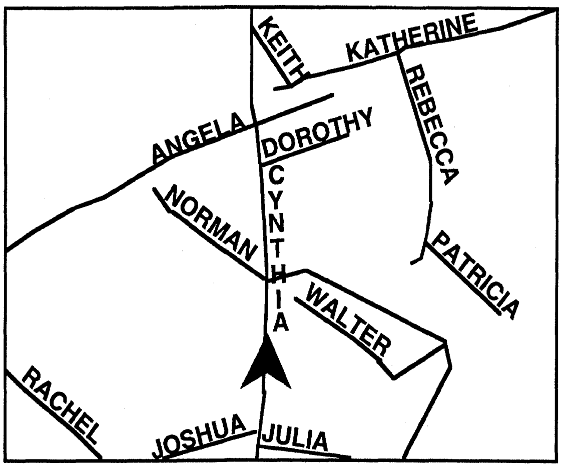
Map 12. 6 Streets, Vertical labels, Non-grid, 18 Point, Male name



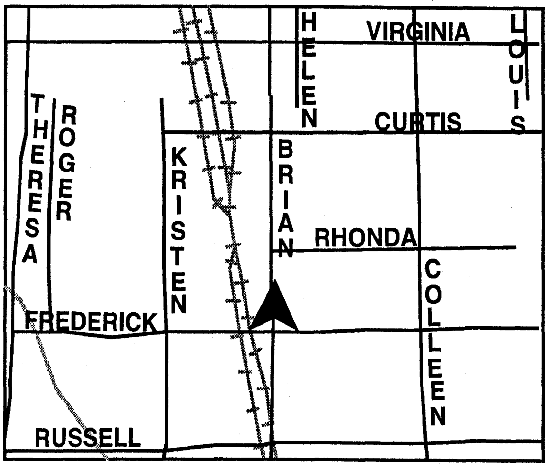
Map 13. 12 Streets, Horizontal labels, Non-grid, 12 Point, Female name



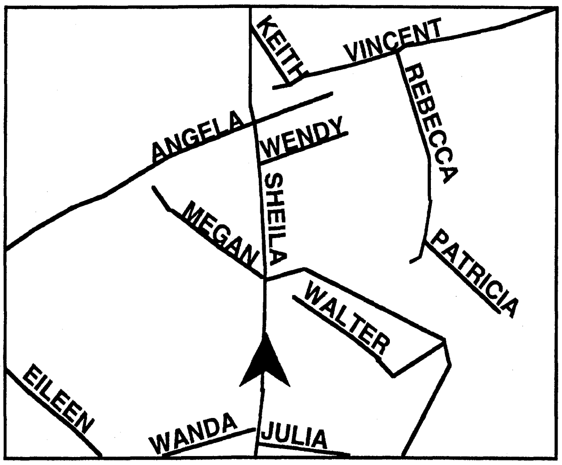
Map 14. 12 Streets, Horizontal labels, Grid, 12 Point, Male name



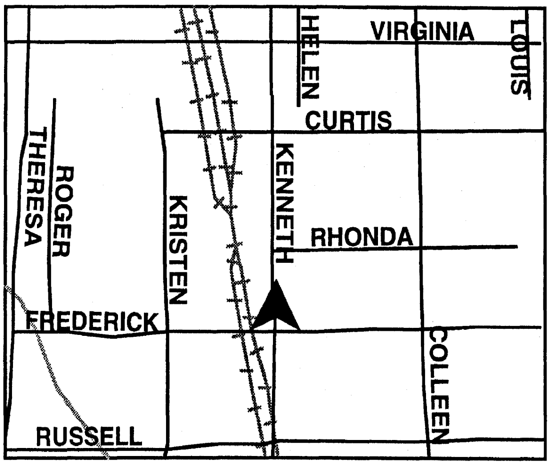
Map 15. 12 Streets, Stacked labels, Non-grid, 12 Point, Female name



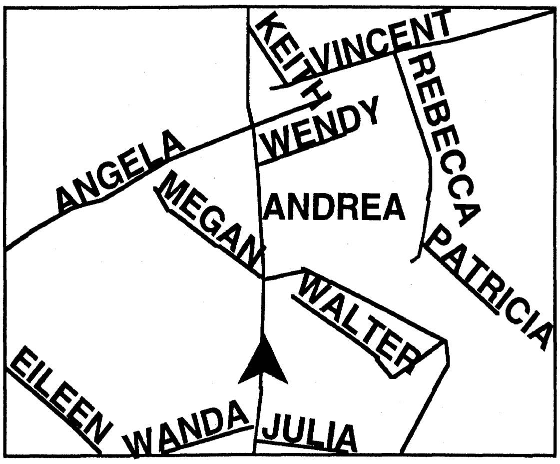
Map 16. 12 Streets, Stacked labels, Grid, 12 Point, Male name



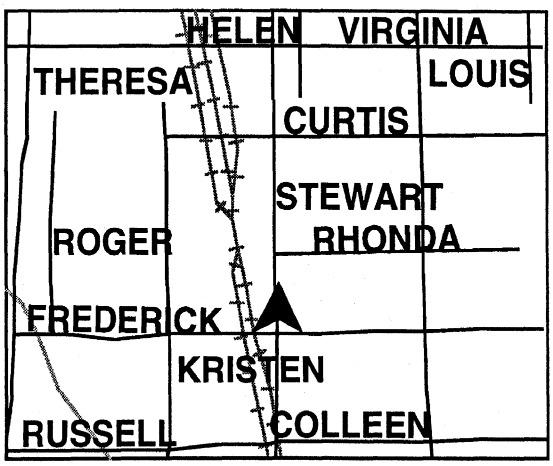
Map 17. 12 Streets, Vertical labels, Non-grid, 12 Point, Female name



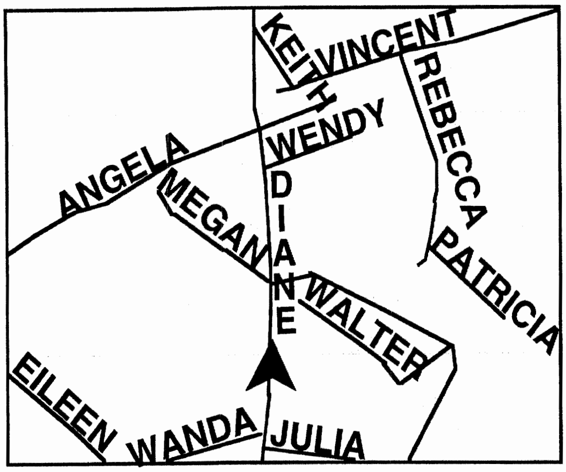
Map 18. 12 Streets, Vertical labels, Grid, 12 Point, Male name



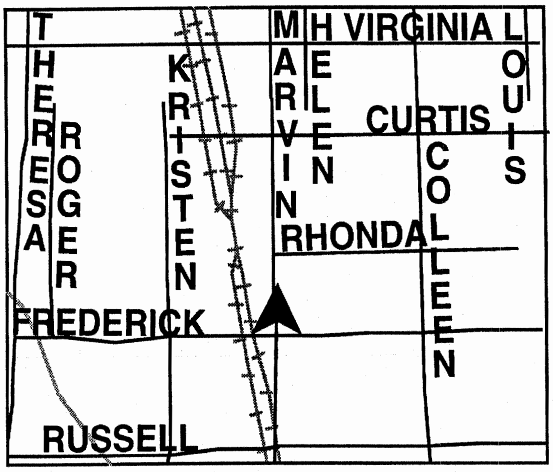
Map 19. 12 Streets, Horizontal labels, Non-grid, 18 Point, Female name



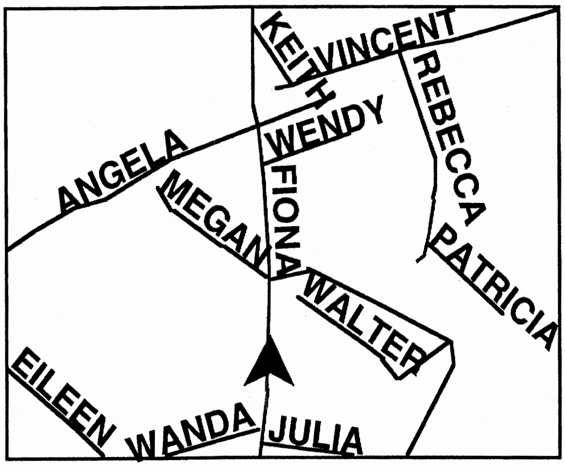
Map 20. 12 Streets, Horizontal labels, Grid, 18 Point, Male name



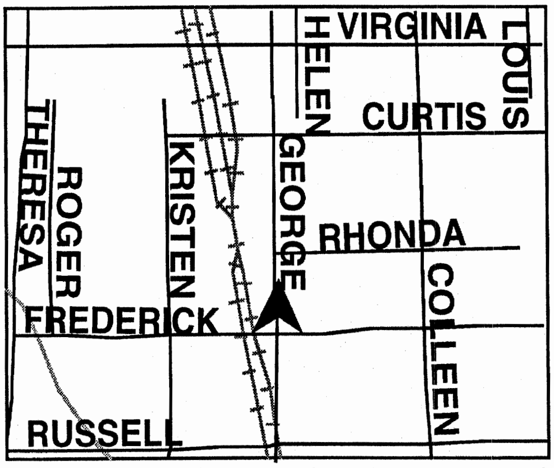
Map 21. 12 Streets, Stacked labels, Non-grid, 18 Point, Female name



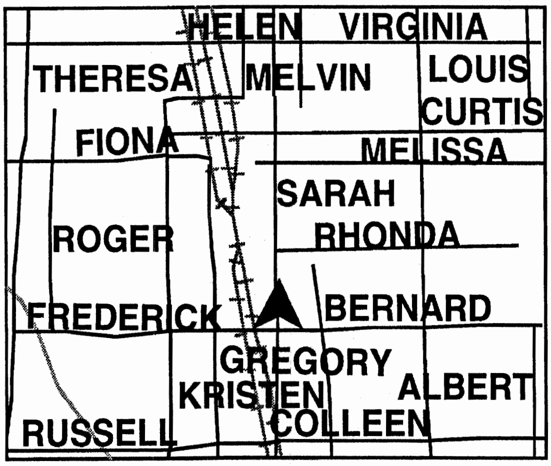
Map 22. 12 Streets, Stacked labels, Grid, 18 Point, Male name



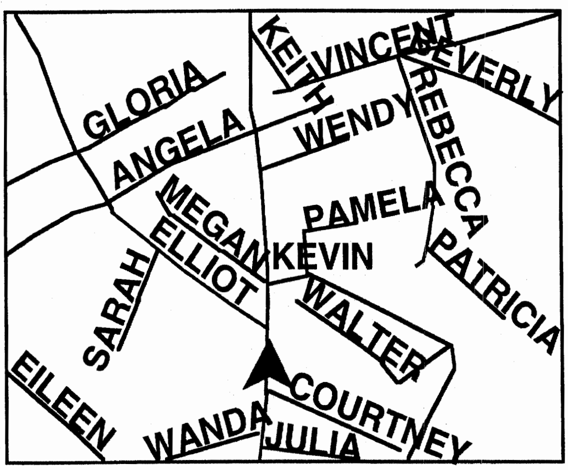
Map 23. 12 Streets, Vertical labels, Non-grid, 18 Point, Female name



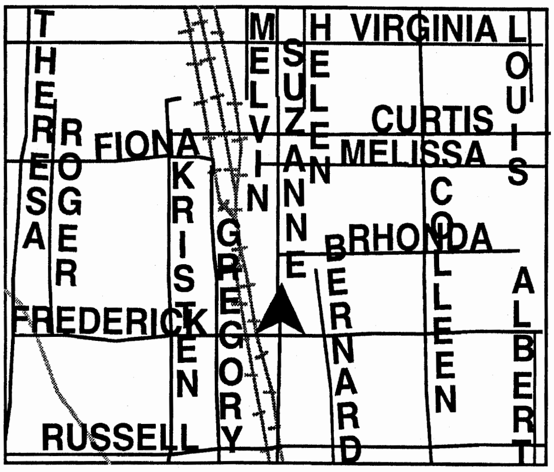
Map 24. 12 Streets, Vertical labels, Grid, 18 Point, Male name



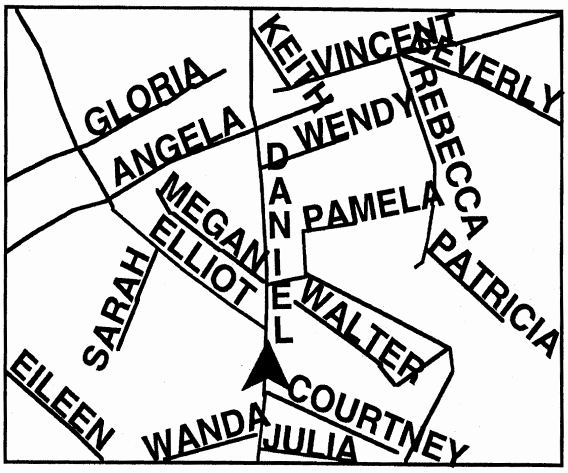
Map 25. 18 Streets, Horizontal labels, Grid, 18 Point, Female name



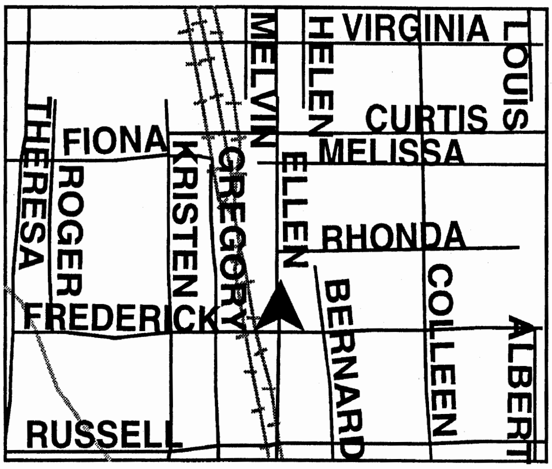
Map 26. 18 Streets, Horizontal labels, Non-grid, 18 Point, Male name



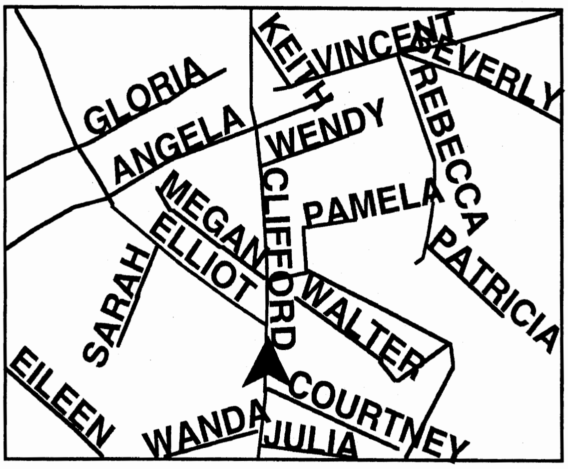
Map 27. 18 Streets, Stacked labels, Grid, 18 Point, Female name



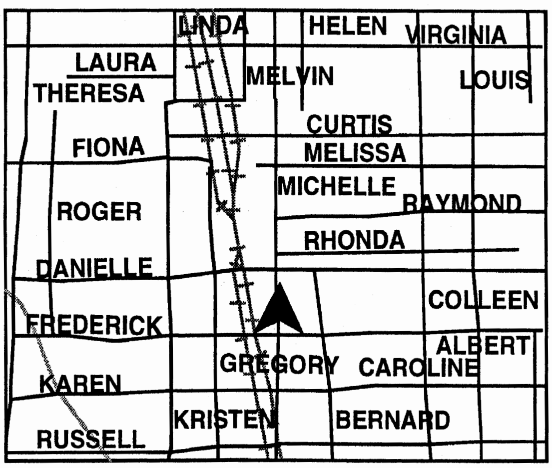
Map 28. 18 Streets, Stacked labels, Non-grid, 18 Point, Male name



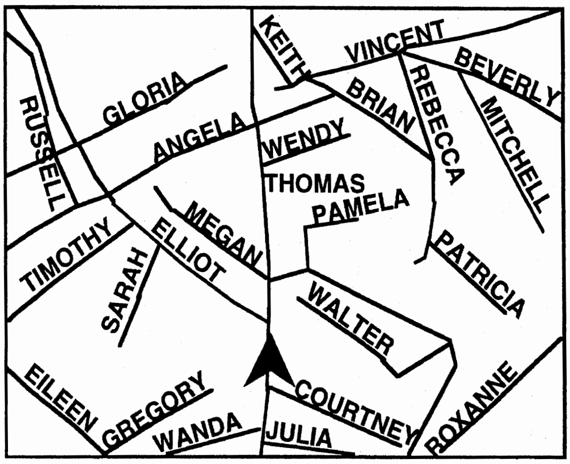
Map 29. 18 Streets, Vertical labels, Grid, 18 Point, Female name



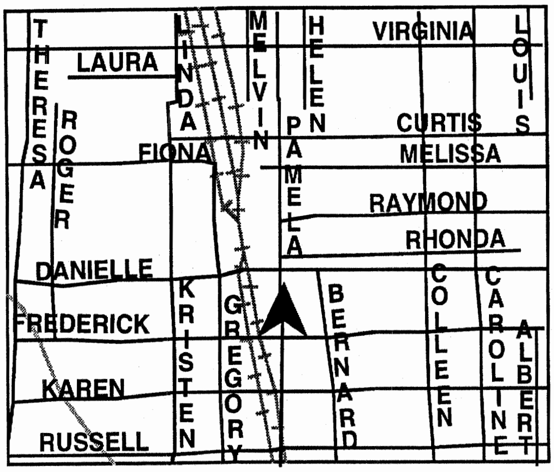
Map 30. 18 Streets, Vertical labels, Non-grid, 18 Point, Male name



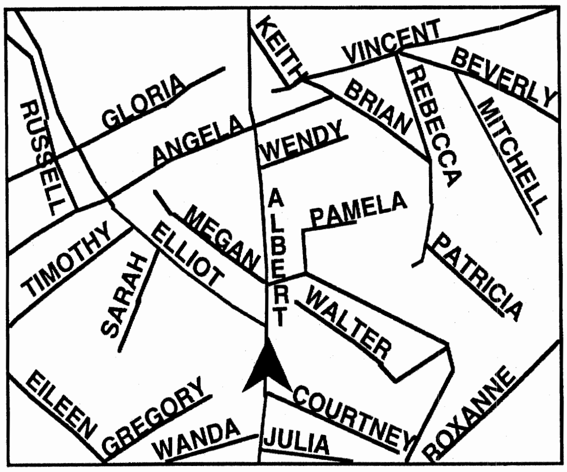
Map 31. 24 Streets, Horizontal labels, Grid, 12 Point, Female name



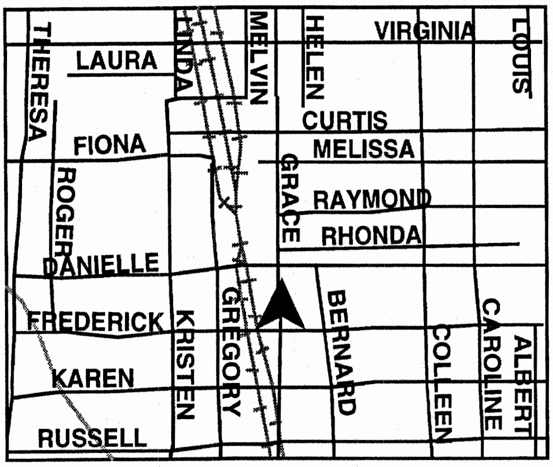
Map 32. 24 Streets, Horizontal labels, Non-grid, 12 Point, Male name



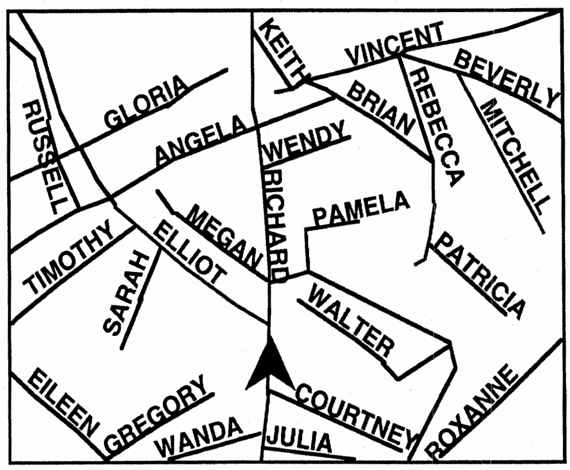
Map 33. 24 Streets, Stacked labels, Grid, 12 Point, Female name



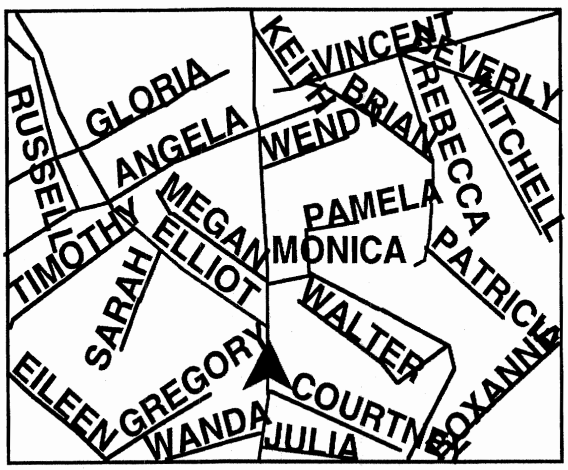
Map 34. 24 Streets, Stacked Labels, Non-grid, 12 Point, Male name



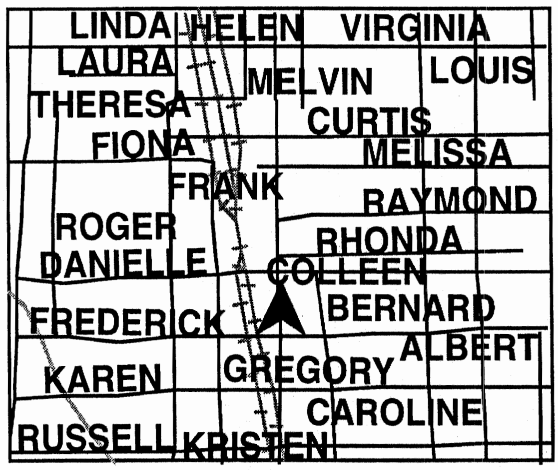
Map 35. 24 Streets, Vertical labels, Grid, 12 Point, Female name



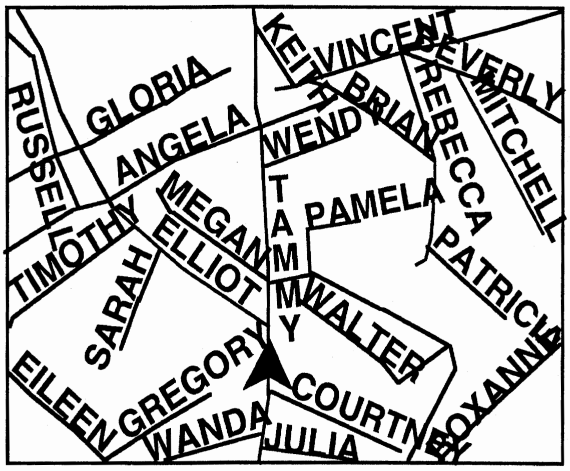
Map 36. 24 Streets, Vertical labels, Non-grid, 12 Point, Male name



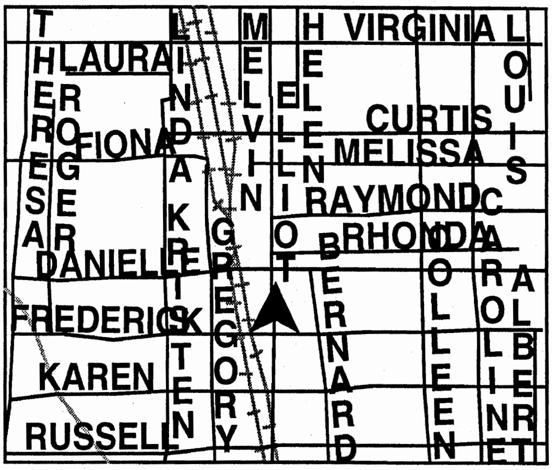
Map 37. 24 Streets, Horizontal labels, Non-grid, 18 Point, Female name



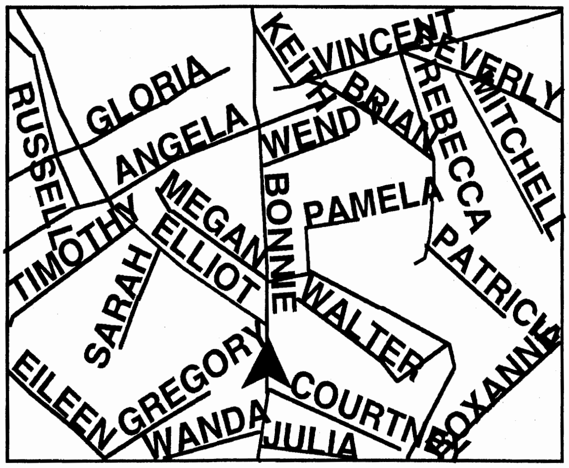
Map 38. 24 Streets, Horizontal labels, Grid, 18 Point, Male name



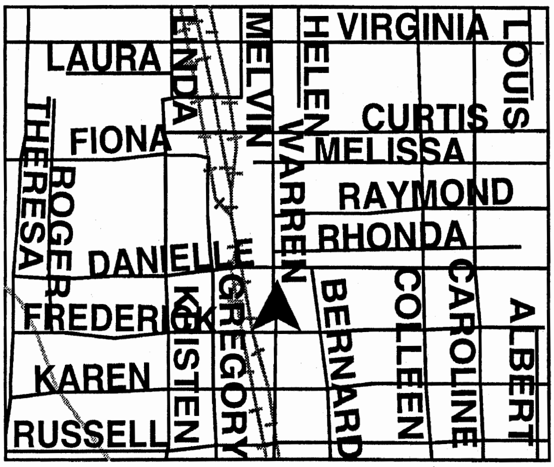
Map 39. 24 Streets, Stacked labels, Non-grid, 18 Point, Female name



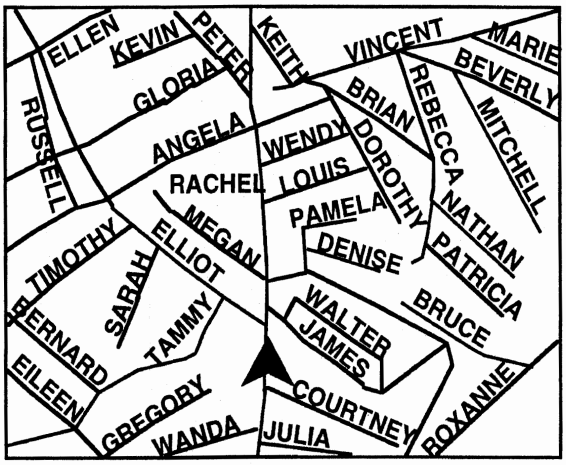
Map 40. 24 Streets, Stacked labels, Grid, 18 Point, Male name



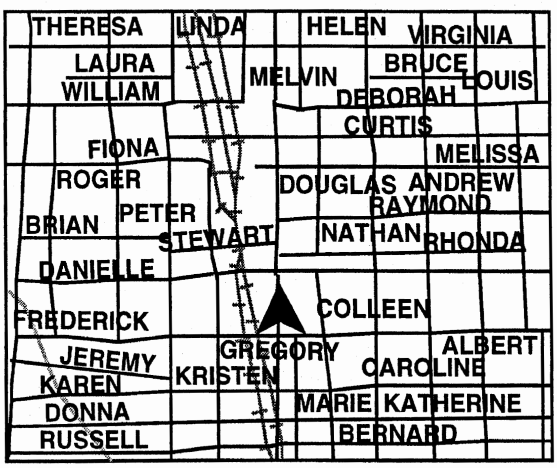
Map 41. 24 Streets, Vertical labels, Non-grid, 18 Point, Female name



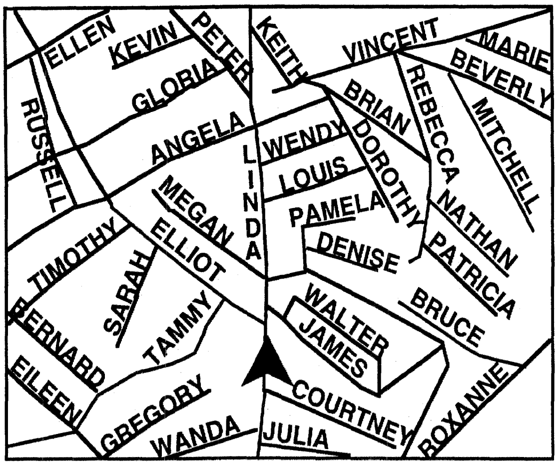
Map 42. 24 Streets, Vertical labels, Grid, 18 Point, Male name



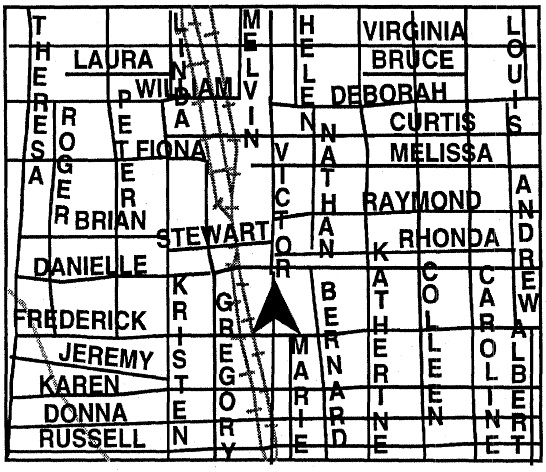
Map 43. 36 Streets, Horizontal labels, Non-grid, 12 Point, Female name



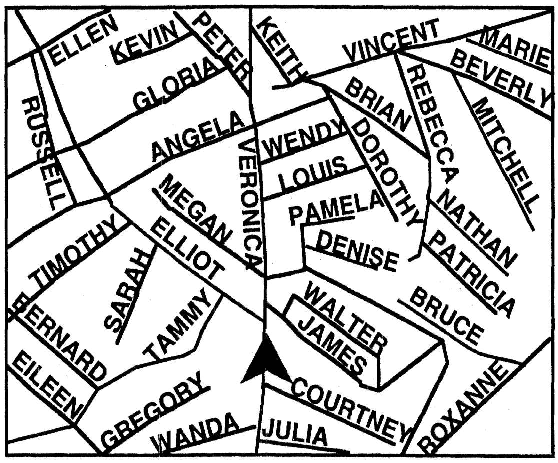
Map 44. 36 Streets, Horizontal labels, Grid, 12 Point, Male name



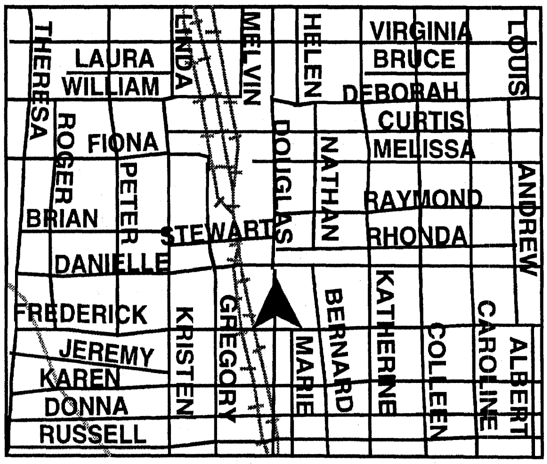
Map 45. 36 Streets, Stacked labels, Non-grid, 12 Point, Female name



Map 46. 36 Streets, Stacked labels, Grid, 12 Point, Male name



Map 47. 36 Streets, Vertical labels, Non-grid, 12 Point, Female name



Map 48. 36 Streets, Vertical Labels, Grid, 12 Point, Male name

APPENDIX B – Street Names

The names shown in Tables 18 and 19 below were chosen from Evans (1994). They were selected to be easily recognizable, not associated with any particular ethnic group, and clearly either female or male. All names contained from five to nine letters, inclusive.

Table 18. Female names.

Andrea	Courtney	Ellen	Jessica	Marie	Paula	Veronica
Angela	Cynthia	Emily	Joanne	Megan	Rachel	Victoria
Barbara	Danielle	Fiona	Judith	Melinda	Rebecca	Virginia
Bethany	Deborah	Florence	Julia	Melissa	Rhonda	Wanda
Betty	Denise	Gloria	Karen	Michelle	Roxanne	Wendy
Beverly	Diane	Grace	Katherine	Monica	Sarah	
Bonnie	Donna	Heidi	Kristen	Nancy	Sheila	
Caroline	Dorothy	Helen	Laura	Nicole	Suzanne	
Charlotte	Eileen	Janet	Linda	Pamela	Tammy	
Colleen	Elaine	Jennifer	Margaret	Patricia	Theresa	

Table 19. Male Names.

Albert	Craig	Eugene	Jonathan	Marvin	Richard	Victor
Andrew	Curtis	Frank	Joseph	Matthew	Robert	Vincent
Benjamin	Daniel	Frederick	Joshua	Melvin	Roger	Walter
Bernard	David	George	Keith	Michael	Ronald	Warren
Bradley	Dennis	Gregory	Kenneth	Mitchell	Russell	William
Brian	Donald	Henry	Kevin	Nathan	Samuel	
Bruce	Douglas	Howard	Lawrence	Norman	Steven	
Charles	Duane	James	Leonard	Peter	Stewart	
Clarence	Edward	Jeffery	Louis	Phillip	Thomas	
Clifford	Elliot	Jeremy	Martin	Raymond	Timothy	

APPENDIX C – Map Design Characteristic Considerations

There are a large number of characteristics that could be considered, along with environmental, driver, and labeling options. Those are shown in Tables 20 to 22 along with thoughts on their priority. Figure 39 shows some of the labeling options. Priorities were based primarily on the likely impact of that characteristic on performance, though how easy the characteristic could be varied (both in practice and in the experiment) was also considered.

Table 20. Map characteristics.

Object	Property	Priority
Number of streets/roads		high
Coding of streets/roads	color (and number of levels)	medium
	width (and number of levels)	medium
Labeling	legibility (font, size)	size–high font–low
	presence of label	high
	label orientation (horizontal, vertical, curved)	high
	length of name	low
	congestion	medium
Map orientation (North-up vs. head-up)		high
Display size (5 vs. 7 vs. 9 inch)		moderate
Landmarks (mostly points)	road-related-stop signs, traffic lights, bridges	high
	transportation interchange (parking, bus terminal, airport, train station)	low
	obvious (gas station, fast food)	medium
	points of interest (stadium, theater, zoo)	low
	toll booths	low
	Large areas (parks, water)	low
Global attributes	region name	medium
	map scale	medium
	political boundaries	low

Table 21. Environmental characteristics.

Characteristic	Priority
Lighting (day vs. night)	medium
Vibration	medium
Map location (Head-up display vs. Instrument panel)	high

Table 22. Driver characteristics.

Characteristic	Priority
Age	high
Gender	high
Map reading performance	low

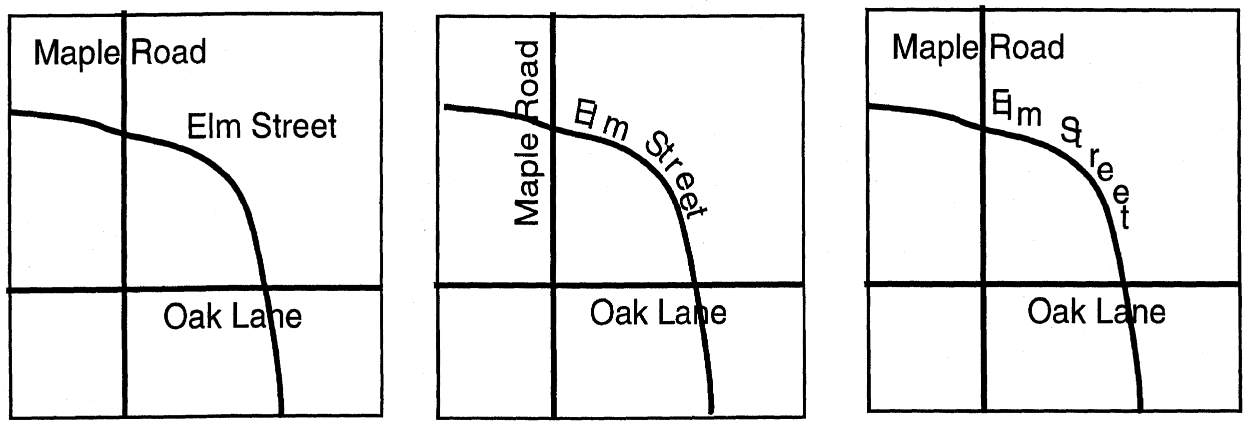


Figure 39. Some label orientation options.

APPENDIX D – Legibility Study Participant Consent Form

Subject: ____________ Date: ____________

MAP LEGIBILITY STUDY
PARTICIPANT CONSENT FORM

The purpose of this experiment is to determine how to maximize the legibility of electronic maps that might appear in cars of the future. You will be driving a simulated car in the laboratory, while being asked to make judgements concerning the legibility of maps. You will be given several short breaks during the course of the experiment. Some people experience motion discomfort in the simulator. If this occurs, tell the experimenter immediately, and she will stop the simulator. You will be paid in full, regardless of whether or not you are able to complete the experiment.

The study takes approximately 1-1/2 hours, and you will be paid $20 for your time. Thank you for your participation.

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

____________________ ____________________

Print your name Date

____________________ ____________________

Sign your name Witness (experimenter)

APPENDIX E – Subject Biographical Form

Map Legibility Study - Biographical Form

University of Michigan Transportation Research Institute
Human Factors Division
Biographical Form

Subject: ☐

Date: ☐

Name: ____________________

Male **Female** (circle one) **Age:** ________

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

In the last 6 months, 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

TITMUS VISION: (Landolt Rings)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	Vision correctors?
T	R	R	L	T	B	L	R	L	B	R	B	T	R	Y / N
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 F – Legibility Study Instructions to Subjects

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

Overview
This is a study concerning electronic maps that is being conducted in a driving simulator. The study will take approximately 1-1/2 hours **to complete and you will be paid $20 for your time. You will be asked to drive the simulator while performing 2 different tasks. For the first task, you will be shown pairs of maps and asked, which of these maps is the most legible? - left or right. For the second task, you will be shown single maps and asked if you feel uncomfortable reading them while driving. This information will be used to design electronic maps in cars of the future that you may drive. Before we start, there are some forms I need you 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 turn the page and 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 the responses are legible and complete.

Vision Test
Next, I'll be checking your vision. 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 in the first diamond that the top circle is complete but the other 3 are broken? In each diamond, tell me the location of the solid circle - top, left, bottom, or right.** Continue until 2 in a row are wrong. Take the last one that was correct as the visual acuity. **OK. Now we'll go down to the simulator laboratory where I'll explain the rest.**

In the Simulator
Please step into the simulator, adjust the seat and fasten your seatbelt. Here is the seat control. Subject adjusts seatbelt and seat. **This is a study to determine how to maximize the legibility of a map. Some of these factors of interest are street name letter size, street width, and the number of streets on the map. You will be shown pairs of slides of maps, side-by-side, while you are driving the simulator, and asked which of the slides is the most legible. Your response will either be "left" or "right."**

When responding, consider how you might use a map:

1. **to find out what street you are on,**
2. **to check the name of an upcoming street, or**

3. to find out where on the map a particular street is located.

When determining which slide is most legible, you should consider these 3 tasks (street you are on, upcoming street, street of unknown location). Base your decision on the entire map, not just the legibility of the street labels.

After you give an answer, we will go on to the next pair. I'll be giving you several short breaks during the experiment. Do you have any questions?

Shut off room lights. Show first pair of slides.

Which map is the most legible?

Record subject response and show next pair of slides.

After all pairs have been shown - **Next, I'll show you various single slides. Tell me, do you feel comfortable that you can read this map and still drive safely, yes or no? Do you have any questions? Let's begin.**

Show slides until subject answers "no" to the question. Show the 8 slides from the matrix that are around the "no" slide.

That completes the experiment. If you could fill out this form, I'll get your payment. Subject fills out form and receives compensation. **Thank you very much for your time. Have a nice day.**

APPENDIX G – Grid ANOVA Table for Legibility Study

Source	df	Sum of Squares	Mean Square	F-value	p-value
Age	1	0.000	0.000		
Gender	1	0.000	0.000		
Age * Gender	1	0.000	0.000		
Subject(Group)	4	0.000	0.000		
Streets	3	13647.7	4549.2	2991.3	<.0001
Streets * Age	3	5.344	1.781	1.171	.3613
Streets * Gender	3	1.531	.510	0.336	.7999
Streets * Age * Gender	3	2.406	.802	0.527	.6718
Streets * Subject(Group)	12	18.250	1.521		
Point Size	1	4935.1	4935.1	261.89	<.0001
Point Size * Age	1	49.000	49.000	2.600	.1821
Point Size * Gender	1	7.562	7.562	0.401	.5608
Point Size * Age * Gender	1	4.000	4.000	0.212	.6689
Point Size * Subject(Group)	4	75.375	18.844		
Thickness	1	260.02	260.02	40.887	.0031
Thickness * Age	1	.766	.766	0.120	.7461
Thickness * Gender	1	13.141	13.141	2.066	.2240
Thickness * Age * Gender	1	8.266	8.266	1.300	.3179
Thickness * Subject(Group)	4	25.438	6.359		
Boldness	1	185.64	185.64	49.299	.0022
Boldness * Age	1	28.891	28.891	7.672	.0503
Boldness * Gender	1	1.266	1.266	0.336	.5932
Boldness * Age * Gender	1	1.266	1.266	0.336	.5932
Boldness * Subject(Group)	4	15.062	3.766		
Streets * Point Size	3	251.719	83.906	71.283	<.0001
Streets * Point Size * Age	3	15.406	5.135	4.363	.0269
Streets * Point Size * Gender	3	2.781	.927	0.788	.5236
Streets * Point Size * Age * Gender	3	.219	.073	0.062	.9789
Streets * Point Size * Subject(Group)	12	14.125	1.177		
Streets * Thickness	3	53.453	17.818	22.359	<.0001
Streets * Thickness * Age	3	9.078	3.026	3.797	.0399
Streets * Thickness * Gender	3	2.891	.964	1.209	.3484
Streets * Thickness * Age * Gender	3	1.141	.380	0.477	.7041
Streets * Thickness * Subject(Group)	12	9.563	.797		
Streets * Boldness	3	45.266	15.089	10.384	.0012
Streets * Boldness * Age	3	1.391	.464	0.319	.8115
Streets * Boldness * Gender	3	12.078	4.026	2.771	.0874
Streets * Boldness * Age * Gender	3	5.453	1.818	1.251	.3348
Streets * Boldness * Subject(Group)	12	17.437	1.453		
Point Size * Thickness	1	8.266	8.266	2.713	.1749
Point Size * Thickness * Age	1	4.516	4.516	1.482	.2904
Point Size * Thickness * Gender	1	1.266	1.266	0.415	.5543

Point Size * Thickness * Age * Gender	1	2.641	2.641	0.867	.4046
Point Size * Thickness * Subject(Group)	4	12.188	3.047		
Point Size * Boldness	1	31.641	31.641	23.276	.0085
Point Size * Boldness * Age	1	8.266	8.266	6.080	.0693
Point Size * Boldness * Gender	1	.141	.141	0.103	.7638
Point Size * Boldness * Age * Gender	1	1.891	1.891	1.391	.3036
Point Size * Boldness * Subject(Group)	4	5.437	1.359		
Thickness * Boldness	1	10.563	10.563	10.903	.0299
Thickness * Boldness * Age	1	6.250	6.250	6.452	.0640
Thickness * Boldness * Gender	1	2.250	2.250	2.323	.2022
Thickness * Boldness * Age * Gender	1	.063	.063	0.065	.8120
Thickness * Boldness * Subject(Group)	4	3.875	.969		
Streets * Point Size * Thickness	3	7.891	2.630	3.301	.0577
Streets * Point Size * Thickness * Age	3	5.016	1.672	2.098	.1539
Streets * Point Size * Thickness * Gender	3	1.703	.568	0.712	.5631
Sts * Pt Size * Thickness * Age * Gender	3	.703	.234	0.294	.8289
Sts * Pt Size * Thick * Subject(Group)	12	9.562	.797		
Streets * Point Size * Boldness	3	1.578	.526	0.412	.7472
Streets * Point Size * Boldness * Age	3	.828	.276	0.216	.8832
Streets * Point Size * Boldness * Gender	3	1.266	.422	0.331	.8034
Sts * Pt Size * Boldness * Age * Gender	3	6.391	2.130	1.669	.2262
Sts * Pt Size * Bold * Subject(Group)	12	15.312	1.276		
Streets * Thickness * Boldness	3	3.219	1.073	1.537	.2555
Streets * Thickness * Boldness * Age	3	.656	.219	0.313	.8154
Streets * Thickness * Boldness * Gender	3	6.719	2.240	3.209	.0619
Sts * Thickness * Bold * Age * Gender	3	.281	.094	0.134	.9377
Sts * Thickness * Bold * Subject(Group)	12	8.375	.698		
Point Size * Thickness * Boldness	1	4.000	4.000	4.741	.0950
Point Size * Thickness * Boldness * Age	1	4.000	4.000	4.741	.0950
Pt Size * Thickness * Boldness * Gender	1	.562	.562	0.667	.4601
Pt Size * Thick * Bold * Age * Gender	1	.062	.062	0.074	.7990
Pt Size * Thick * Bold * Subject(Group)	4	3.375	.844		
Sts * Point Size * Thickness * Boldness	3	11.469	3.823	5.319	.0146
Sts * Pt Size * Thickness * Bold * Age	3	.594	.198	0.275	.8421
Sts * Pt Size * Thick * Bold * Gender	3	6.844	2.281	3.174	.0635
Sts * Pt Size * Thick * Bold * Age * Gend.	3	3.719	1.240	1.725	.2150
Sts * Pt Size * Thick * Bold * Subj(Group)	12	8.625	.719		

APPENDIX H – Unpaired t-tests for Grid Maps in Legibility Study

Variable = number of streets

Source	df	t-value	p-value
18, 24	126	7.610	<.0001
18, 30	126	16.252	<.0001
18, 36	126	27.237	<.0001
24, 30	126	7.592	<.0001
24, 36	126	14.197	<.0001
30, 36	126	5.111	<.0001

Variable = point size

Source	df	t-value	p-value
12, 18	254	9.140	<.0001

Variable = street thickness

Source	df	t-value	p-value
1, 2	254	1.832	.0681

Variable = boldness

Source	df	t-value	p-value
bold, regular	254	1.545	.1236

APPENDIX I – Non-grid ANOVA Table for Legibility Study

Source	df	Sum of Squares	Mean Square	F-value	p-value
Age	1	.004	.004	1.000	.3739
Gender	1	.004	.004	1.000	.3739
Age * Gender	1	.004	.004	1.000	.3739
Subject(Group)	4	.016	.004		
Streets	3	13208.6	4402.9	14896	<.0001
Streets * Age	3	.887	.296	1.000	.4262
Streets * Gender	3	1.199	.400	1.352	.3040
Streets * Age * Gender	3	1.137	.379	1.282	.3250
Streets * Subject(Group)	12	3.547	.296		
Point Size	1	5919.4	5919.4	1407.0	<.0001
Point Size * Age	1	7.910	7.910	1.880	.2422
Point Size * Gender	1	2.848	2.848	0.677	.4569
Point Size * Age * Gender	1	2.066	2.066	0.491	.5220
Point Size * Subject(Group)	4	16.828	4.207		
Thickness	1	177.22	177.22	27.513	.0063
Thickness * Age	1	13.598	13.598	2.111	.2199
Thickness * Gender	1	7.223	7.223	1.121	.3493
Thickness * Age * Gender	1	10.973	10.973	1.703	.2619
Thickness * Subject(Group)	4	25.766	6.441		
Boldness	1	111.57	111.57	10.733	.0306
Boldness * Age	1	.660	.660	0.064	.8135
Boldness * Gender	1	5.348	5.348	0.514	.5129
Boldness * Age * Gender	1	.004	.004	.00038	.9855
Boldness * Subject(Group)	4	41.578	10.395		
Streets * Point Size	3	269.824	89.941	62.625	<.0001
Streets * Point Size * Age	3	4.730	1.577	1.098	.3878
Streets * Point Size * Gender	3	3.980	1.327	0.924	.4589
Streets * Point Size * Age * Gender	3	4.824	1.608	1.120	.3797
Streets * Point Size * Subject(Group)	12	17.234	1.436		
Streets * Thickness	3	43.418	14.473	31.310	<.0001
Streets * Thickness * Age	3	1.855	.618	1.338	.3082
Streets * Thickness * Gender	3	2.168	.723	1.563	.2494
Streets * Thickness * Age * Gender	3	2.855	.952	2.059	.1593
Streets * Thickness * Subject(Group)	12	5.547	.462		
Streets * Boldness	3	16.137	5.379	3.313	.0571
Streets * Boldness * Age	3	4.855	1.618	0.997	.4275
Streets * Boldness * Gender	3	1.855	.618	0.381	.7686
Streets * Boldness * Age * Gender	3	4.637	1.546	0.952	.4466
Streets * Boldness * Subject(Group)	12	19.484	1.624		
Point Size * Thickness	1	2.848	2.848	1.221	.3311
Point Size * Thickness * Age	1	2.441	2.441	1.047	.3641
Point Size * Thickness * Gender	1	.191	.191	0.082	.7887

Point Size * Thickness * Age * Gender	1	.473	.473	0.203	.6759
Point Size * Thickness * Subject(Group)	4	9.328	2.332		
Point Size * Boldness	1	14.535	14.535	8.142	.0462
Point Size * Boldness * Age	1	.473	.473	0.265	.6340
Point Size * Boldness * Gender	1	3.285	3.285	1.840	.2464
Point Size * Boldness * Age * Gender	1	.473	.473	0.265	.6340
Point Size * Boldness * Subject(Group)	4	7.141	1.785		
Thickness * Boldness	1	3.754	3.754	0.772	.4292
Thickness * Boldness * Age	1	3.285	3.285	0.676	.4573
Thickness * Boldness * Gender	1	.473	.473	0.097	.7708
Thickness * Boldness * Age * Gender	1	2.441	2.441	0.502	.5177
Thickness * Boldness * Subject(Group)	4	19.453	4.863		
Streets * Point Size * Thickness	3	6.293	2.098	5.050	.0172
Streets * Point Size * Thickness * Age	3	1.387	.462	1.113	.3822
Streets * Point Size * Thickness * Gender	3	.449	.150	0.361	.7827
Sts * Pt Size * Thickness * Age * Gender	3	.230	.077	0.185	.9046
Sts * Pt Size * Thick * Subject(Group)	12	4.984	.415		
Streets * Point Size * Boldness	3	6.293	2.098	2.537	.1058
Streets * Point Size * Boldness * Age	3	2.293	.764	0.924	.4586
Streets * Point Size * Boldness * Gender	3	2.793	.931	1.126	.3774
Sts * Pt Size * Boldness * Age * Gender	3	1.918	.639	0.773	.5310
Sts * Pt Size * Bold * Subject(Group)	12	9.922	.827		
Streets * Thickness * Boldness	3	.887	.296	0.276	.8417
Streets * Thickness * Boldness * Age	3	.418	.139	0.130	.9404
Streets * Thickness * Boldness * Gender	3	6.043	2.014	1.880	.1868
Sts * Thickness * Bold * Age * Gender	3	3.512	1.171	1.092	.3898
Sts * Thickness * Bold * Subject(Group)	12	12.859	1.072		
Point Size * Thickness * Boldness	1	.473	.473	0.538	.5040
Point Size * Thickness * Boldness * Age	1	1.410	1.410	1.604	.2740
Pt Size * Thickness * Boldness * Gender	1	.035	.035	0.040	.8512
Pt Size * Thick * Bold * Age * Gender	1	.473	.473	0.538	.5040
Pt Size * Thick * Bold * Subject(Group)	4	3.516	.879		
Sts * Point Size * Thickness * Boldness	3	1.168	.389	2.034	.1629
Sts * Pt Size * Thickness * Bold * Age	3	1.918	.639	3.340	.0560
Sts * Pt Size * Thick * Bold * Gender	3	1.230	.410	2.143	.1480
Sts * Pt Size * Thick * Bold * Age * Gend.	3	.605	.202	1.054	.4044
Sts * Pt Size * Thick * Bold * Subj(Group)	12	2.297	.191		

APPENDIX J – Unpaired t-tests for Non-grid Maps in Legibility Study

Variable = number of streets

Source	df	t-value	p-value
18, 24	126	6.651	<.0001
18, 30	126	15.158	<.0001
18, 36	126	25.449	<.0001
24, 30	126	7.383	<.0001
24, 36	126	13.638	<.0001
30, 36	126	4.862	<.0001

Variable = point size

Source	df	t-value	p-value
12, 18	254	10.295	<.0001

Variable = street thickness

Source	df	t-value	p-value
1, 2	254	1.503	.1341

Variable = boldness

Source	df	t-value	p-value
bold, regular	254	1.191	.2350

APPENDIX K – Participant Consent Form

Subject: ____________ Date: ____________

MAP LEGIBILITY STUDY
PARTICIPANT CONSENT FORM

The purpose of this experiment is to determine how to maximize the legibility of electronic maps that might appear in cars of the future. You will be driving a simulated car in the laboratory, while being asked to locate particular streets and give the gender of the street labels on maps. You will be given several short breaks during the course of the experiment. Some people experience motion discomfort in the simulator. If this occurs, tell the experimenter immediately, and she will stop the simulator. You will be paid in full, regardless of whether or not you are able to complete the experiment.

The study takes approximately 2-1/2 to 2-3/4 hours, and you will be paid $40 for your time. Thank you for your participation.

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

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

APPENDIX L – Instructions to Subjects

Experiment 1, Map Reading- 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 a study concerning electronic maps. This information will be used to design electronic maps in cars of the future that you may drive. The study will take approximately 3 hours to complete and you will be paid $40 for your time. You will be asked to drive the simulator while performing 3 different map reading tasks. You will also have a practice before two of the tasks. For the first task, I'll show slides of maps and ask you a question about the street you are driving on. For the second task, you will be asked to locate the name of a particular cross street. For the third, your task will be to describe the location of a particular street. Before we start, there are some forms I need you 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 turn the page and fill out the biographical form. One point I want to emphasize is that some people experience motion sickness while driving the simulator. If you feel uncomfortable, there will be no problem stopping the experiment. You will be paid the full amount, even if you are unable to complete the study. If you have any questions, feel free to ask them at any time.

Provide consent and biographical forms. Check that the responses are legible and complete.

Vision Test

Next, I'll be checking your vision. 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 in the first diamond that the top circle is complete but the other 3 are broken? In each diamond, tell me the location of the solid circle - top, left, bottom, or right.** Continue until 2 in a row are wrong. Take the last one that was correct as the visual acuity. **OK. Now we'll go down to the simulator laboratory where I'll explain the next phase.**

In the Simulator

Please step into the simulator, adjust the seat and fasten your seatbelt. Here is the seat control. Subject adjusts seatbelt and seat. **This is a study to determine how different features affect the ease of reading a map. Some of these factors of interest are street name letter size, the number of streets on the map, and the orientation of the street name label.**

For your first practice session, you'll be shown slides with one name on

each slide. The name will either be a male or female name. After the slide appears, your task is to determine whether the name is male or female and to respond by pressing the appropriate button on the board on your right. Quickly press and release the left key with your pointer finger if the name you see is male, such as John. If the name is female, say Jane, press the right key with your middle finger. Demonstrate to the subject. **You'll be driving the simulator as you do these tasks. Please drive 30 mi/hr during the sessions. Also, make sure to keep your eyes on the road when a map is not being shown. You will be alerted that a new map is being shown by a short tone. You'll hear a different, longer tone if you respond incorrectly during any of the tasks. If you respond incorrectly, do not re-enter your response. Also, keep in mind that your main task is to drive safely. After we finish the practice session, I'll give you instructions for the first task. Do you have any questions? I'll be giving you a few minutes of simulator practice time before we start the practice sessions. As a reminder, some subjects may experience a bit of motion discomfort initially, but this normally subsides after a few minutes. If at any time you need to take a break or do not feel as though you can continue with the study, please tell me and I'll stop the simulator. So if you feel you're ready, could you take ahold of the wheel and I'll start the simulator.**

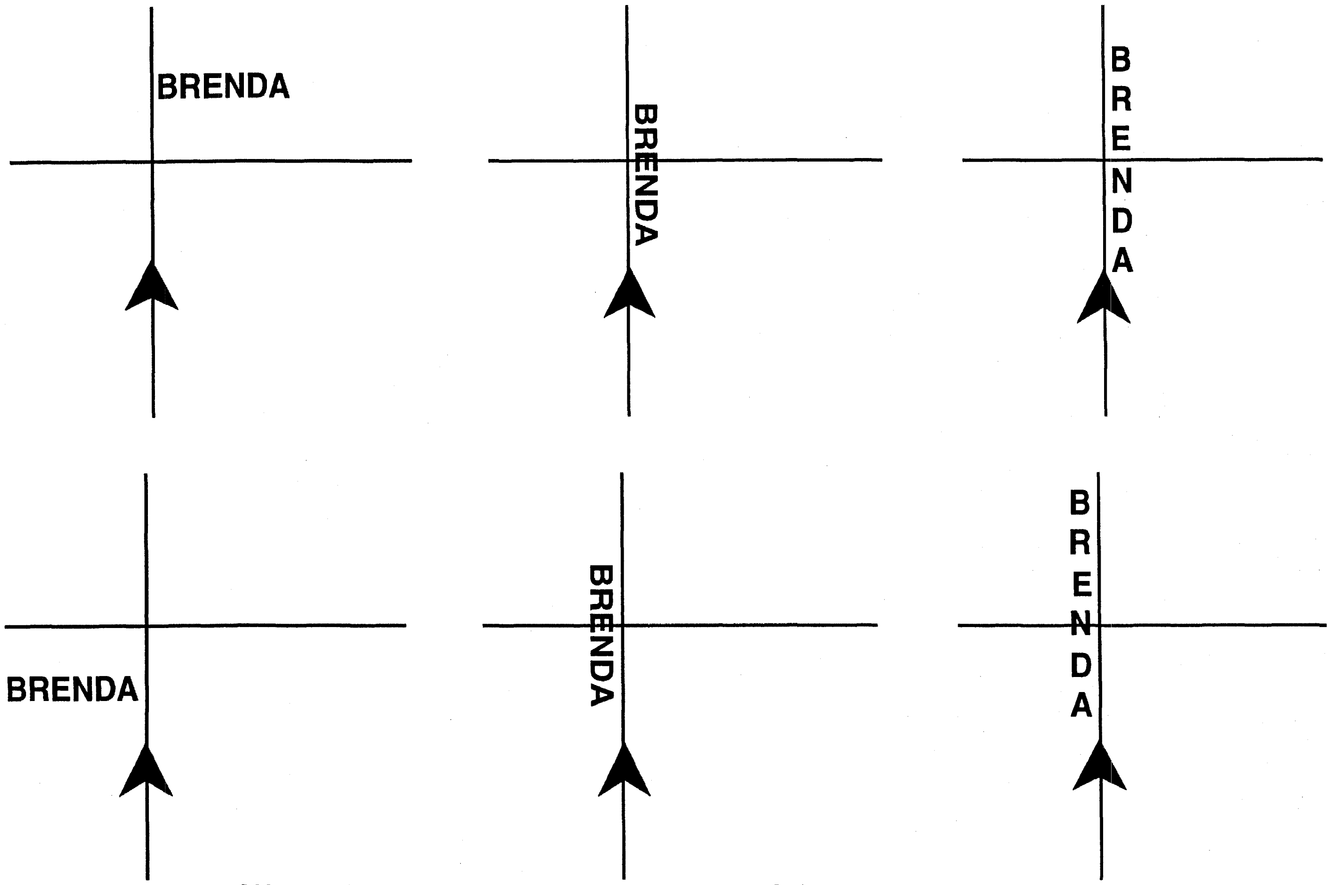
Start simulator. Let subject drive for one minute. Take a short break, ask how they're feeling. Let subject drive for another minute, then start the practice task. Just before the pratice starts say:

Remember,

- **driving safely at 30 mi/hr is your priority, even though the sign posted on the side of the road says 35 mi/hr,**
- **after hearing the tone, look at the map for the street that you're on,**
- **press the left key if the name is male and the right if it is female,**
- **and respond as rapidly and accurately as possible.**

Complete practice task for one-street task.

For the first task, you'll be shown slides of maps with their street labels in different orientations. Your task is to respond using the response board in the same manner as you did during the first practice session, to the following question: Is the name of the street that you are traveling on male of female? Let me show you a few examples.



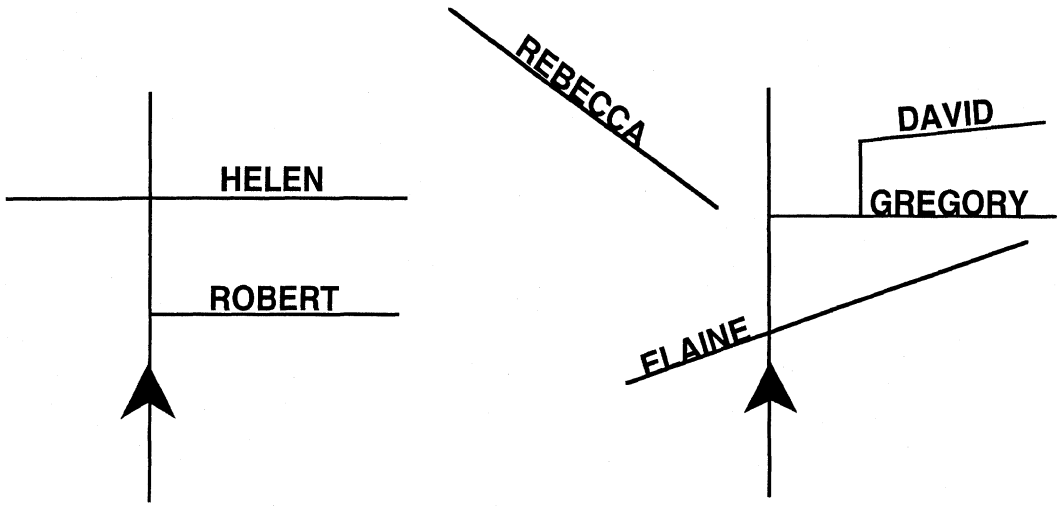
Here are six different ways to show you are driving on Brenda Street, the vertical line. The triangle-shaped icon represents your current location and points in the direction of your travel. The name label for the street won't necessarily be located near the location icon.

You'll be driving the simulator during this task. Please drive 30 mi/hr and stay in your lane, your primary task. Keep your eyes on the road when a map is not being shown. Respond to the map as rapidly and accurately as possible by pressing the keys for male and female names. Do you have any questions?

Run the on-street task.

We'll take a short break and then start the second task.

During the second task, you will be asked: Is the name of a certain cross street (for example, the first or tenth) male or female? I will tell you the number of the cross street that you should be looking for before each trial. A cross street is a street that intersects or touches the street that you are on. It may not necessarily be horizontal. Let me show you a few examples. Show diagram.



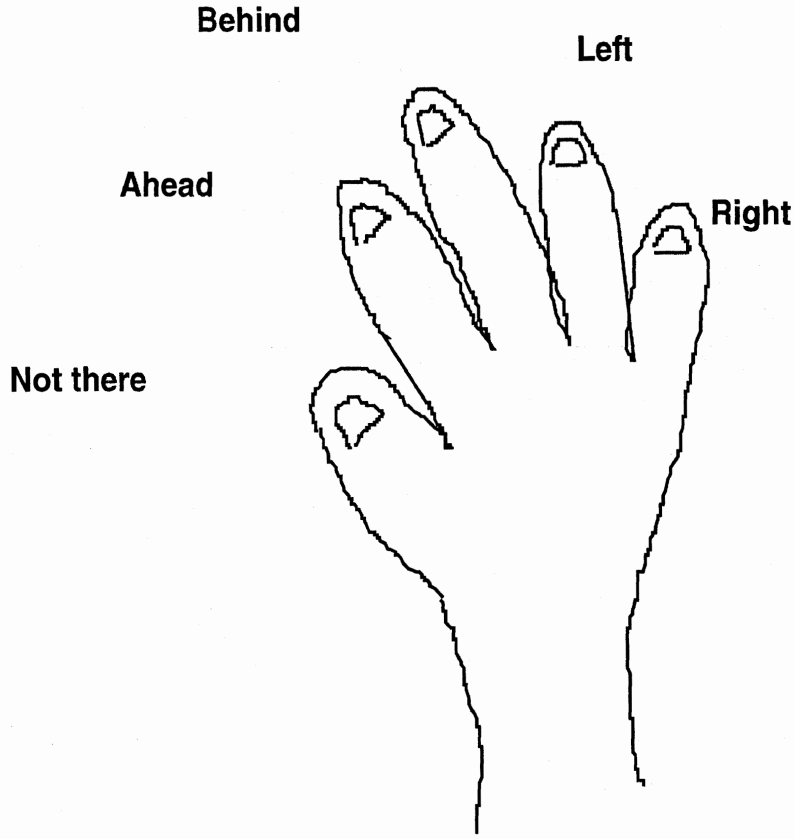
In the figure on the left, both Helen and Robert are cross streets. Robert is the first cross street, while Helen is the second. All of the cross streets in this task will be ahead of the location icon. In the example on the right, Elaine and Gregory are cross streets, while Rebecca and David are not; they do not cross the vertical street in the center. Elaine is the first cross street and Gregory is the second. If you look at the response board, you'll notice that I've added a third response key. For this task, the three possible responses are male, female, and "not there." If I ask you to find the third cross street and the triangle is your current location, and there are only two cross streets on the map, your response would be not there. In this case, you would press the left-most key with your thumb. The male and female keys will be used the same as they were during the first task. In the figure on the right, if I asked you to tell me the gender of the fourth cross street, your response would be "not there." Do you understand the definition of a cross street? Give further explanation if the subject doesn't understand. **You may wish to reorient the response board so it's more comfortable for you.**

Great, let's start the second task.

Run the second task.

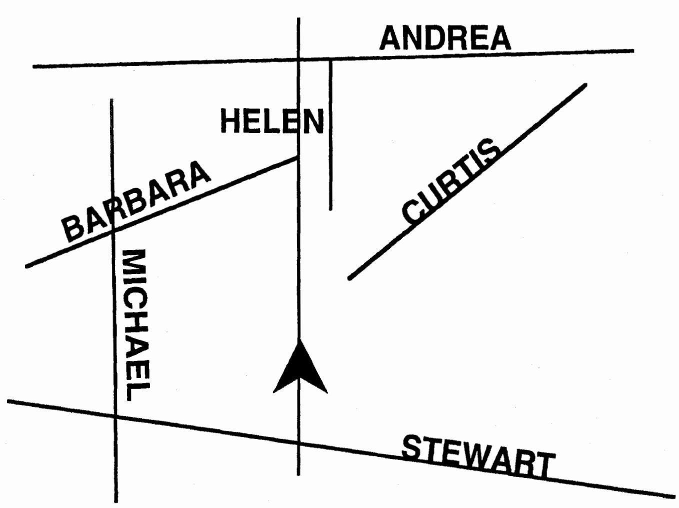
Let's task a quick break, and then start the practice session for the third task.

The third task involves finding a street on a map. For the practice session for the third task, I'll show you a simple map with the location icon on it. A darkened, thicker line will appear ahead, behind, to the left, or to the right of the location icon. Press the key corresponding to the location of the dark line (ahead, behind, left, or right). The responses associated with each finger of your right hand are shown in this diagram. If a darkened line does not appear on the slide, you should respond with the "not there" key. Show diagram.



Run the practice session for task 3.

OK. Let's talk about the third task now. It is very similar to the practice session you just completed. The response buttons are exactly the same. During this task, your task will be to tell the location of a street relative to your location. For example, where is Curtis? I will be speaking the name of the street to look for. Respond by pressing the appropriate keys: ahead, behind, left, right, or "not there." Keep in mind you're looking for the location of the street itself, not the label. Let me show you a few examples. Show diagram.



The street that lies ahead is only classified as such if it crosses or touches the street you're driving on ahead of the location icon. Barbara and Andrea are examples of a street ahead. The behind street is the same thing only behind the location icon. Stewart is a street that is classified as behind. Curtis, though it is ahead of the location icon, would be classified as right, since it doesn't cross or touch the street you're on. Michael is a left street. Helen is a right street, though some of it's label falls to the left of the street you're on. Do you understand how to classify the streets? Give further examples if subject is unclear. **Let's get started then.**

That completes the experiment. If you could fill out this form, I'll get your payment. Subject fills out form and receives compensation. **Thank you very much for your time. Have a nice day.**

APPENDIX M – Map Reading Task Assessments

Task selection was done in three steps:

1. Identify the tasks the drivers perform.
2. Reduce the list of tasks to a set of unique options that are important to real driving.
3. Determine how task performance can be measured using existing equipment (to minimize development cost and time) so the results are reliable.

Step 1: Identify the tasks the drivers perform.

Prior to this experiment, considerable thought was given to how people might use maps. This is important because the tasks examined in experiments should mimic actual map use. Table 23 shows some of the questions that might be answered with an automotive map. Planning tasks (how do I get from x to y, how do I get around the congestion on "x" street) have not been included in this list as they were consider too attention demanding to be performed while driving.

Table 23. Map Reading Tasks.

Street	Property and Modifiers	Example(s)
on-street	name/number	What is the name/number of the street you are on?
	direction	Does Main Street go east-west or north-south?
	distance to	How far is it to Main Street? How far is it to the next traffic light? How far is it to the next gas station?
	congestion	Is there congestion ahead?
cross street	relative number -> name/number first, second, third... before/after	What is the name of the street you just passed? What is the route number for the street two streets ahead?
	name -> relative number	How many streets is it to Main Street? How many streets back is Green Road?
	landmark -> number	How many streets are there to the Sunoco station?
	landmark -> name	What is the name of the street on which the Sunoco is located?
	name -> landmark	Is there a gas station on Main Street?
	number -> landmark	Is there a gas station at the second intersection ahead?
	name 1 -> name 2	What route number is Plymouth Road?

cross street	direction	Does the next cross street go east-west or north-south? If you turn right, in which direction will you be heading (north, south, east, or west)?
	distance to	How far is it from your current location?
	congestion	Is there congestion on Plymouth Road?
complex questions	street before/after	What is the name of the second street before Green Road?
		Between Green Road and the street with a Sunoco station at the corner is a street whose name starts with a "D." What is its name?
		Where is Main Street? (ahead, behind, to left, to right)

Note: Other global attributes/properties include the name of the region in which the driver is located and the map scale selected.

Step 2: Reduce the list of tasks

It would not be feasible to examine all of these tasks in experiments, and furthermore, there are similarities among them that make exhaustive examination unnecessary. Tasks can be grouped along several dimensions: whether search is structured (looking to a particular place) or unstructured (finding where on the map the street is located), and whether search involves counting (some number of cross streets). Tasks also differ in terms of their output (street name, number of streets, whether a street is ahead or behind, etc.).

Given a need to tap these qualities and to limit the number of tasks to be explored, four of the most important and common tasks are suggested for further exploration. They are listed in Table 24.

Table 24. Four key tasks.

Task Category	**Output**	**Typical Query**
on-street	name/number	What is the name/number of the street you are on?
cross street	name -> relative number	How many streets is it to Main Street? How many streets back is Green Road?
cross street	relative number -> name/number first, second, third... before/after	What is the name of the street you just passed? What is the route number for the street two streets ahead?
any street	location (ahead, behind, to left, to right)	Where is Main Street?

Table 25 shows a detailed description of the steps that might be executed for each of these tasks. Notice that the two cross street tasks are similar as only the subtask order differs (either counting streets and looking for a street name, or checking street names and incrementing a mental counter when a match does not occur). Consequently, only one of the cross street tasks was examined.

Table 25. Steps in Executing Tasks.

Task	Typical Query	Steps
on-street	What street are you on?	1. search for current location (center or not center of map) (and find it) 2. identify direction to search (depends if the map is north-up or head-up) 3. search in desired direction for object (and find it) 4. identify appropriate response 5. respond
cross street	How many streets is it to...?	1. search for current location (center or not center of map) (and find it) 2. identify direction to search (depends if the map is north-up or head-up) 3. search in desired direction for object (and find it) 4. find center again 5. count number of streets 6. respond
cross street	What street is x streets ahead?	1. search for current location (center or not center of map) (and find it) 2. identify direction to search (depends if the map is north-up or head-up) 3. search in desired direction for object 4. find a street 5. Is that it? yes–go to response step 6. no–index counter and search again 7. identify appropriate response 8. respond
any street (global search)	Where is Main Street?	1. look at a section 2. does it have the desired feature? 3. no–index counter, repeat step 1 4. yes–read name 5. respond

Step 3: Determine how task performance can be measured.

In the initial experiment, response time (and errors) served as the primary performance measures, though in future experiments, eye fixation data may be obtained. Eye fixation data (number of fixations to the map required and their duration) may be the most direct measures of the attentional demands of a map. There are numerous ways that eye fixations can be recorded (direct view, corneal reflection-based cameras, etc.)

(Green, 1992; Williams and Hoekstra, 1994). However, at the time this data was collected, only direct view recording was available, and reduction of the vast amount of data required was not feasible within the schedule and budget of this project. In direct view, a camera is aimed at the subject to record where they are looking. The videotape is played back frame by frame, and the number of frames for which the subject looks to each location are counted. Data reduction time for this approach is 30-40 hours for each hour of subject time.

In this particular experiment, response time was used as a surrogate measure. While drivers may not look at a display continuously while searching a map, the time from when they begin to search until they make a decision is still a useful measure.

Given response time is the measure of choice, how should subjects respond? It is important that the decisions resemble those real drivers make, and that that performance be easy to measure. It is often suggested in these situations that drivers speak their response. Unfortunately, without expensive hardware, it is difficult to identify the onset of a response. ("What is the name of the second cross street ahead?" "Uhhh, Maple.") Because responses are said quickly, it is difficult for responses to be scored accurately and for the beginning of each response to be timed accurately.

As a consequence, a manual response was favored. It is clear than any response that is complex (e.g., typing in a street name, memorizing names and associating them with response keys) would take a long time to learn and add variability to the subject's performance. The approach selected was to have all street names be common male or female names, a frequent practice in the U.S. This lead to an easy solution of how it could be determined that subjects found a designated street (on which they were driving or the nth cross street). If the street name was male, they pressed one key. If it was female, they pressed another. Since the gender of names is well known and there is ample data on their frequency, the times associated with the final subtask would be minimal and of low variability. Hence, the focus of the task would be on the actual reading of the map, not experimental artifacts to determine what was read.

Other tasks were also considered such as indicating if the street name was an animal (Bear Street), a plant (Maple Road), or a mineral (Iron Avenue), names common in the U.S. However, such tasks would be more of a test of subject knowledge rather than an evaluation of map design.

APPENDIX N – Error and Outlier Trials

A total of 38 trials from the data set, 12 error trials and 26 outliers, were invalid for one of a number of reasons.

One trial was omitted because the recorded response time was less than 200 ms. It was felt that any response time less than this was impossible to achieve with any degree of accuracy and the trial was likely an accidental keypress.

Four trials were omitted because the subject did not realize that a slide was being shown. When a subject made no indication (head or eye movement) of looking at the slide being shown, the experimenter asked if the subject realized that a slide was showing. The subject would then look down at the screen and respond accordingly. This only happened to some older subjects who may not have been able to hear the auditory tone associated with beginning of a slide. The response times for these trials were all greater than 19,000 ms.

Two trials were omitted because of an invalid response to a slide. In Task 1, the subject was only given two response options, the index finger or middle finger. There were two instances in Task 1 where a response was recorded from the ring finger. Since this was not a possible response for the task, the trial was invalidated. Since the keypad was configured for each task so that only the appropriate keypresses were possible, it is not known what caused this irregular response.

One trial was omitted because a slide fell out of the carousel for one subject due to mishandling. A blank screen was shown to the subject as a result of the missing slide. The missing slide was found and replaced before the next subject was run.

Four trials were omitted because the driving simulation ended before all the slides had been presented. This occurred for one subject who was consistently slower in responding.

A total of 26 trials were outliers; 11 from Task 1, 1 from Task 2, and 14 from Task 3. Trials were removed from the Task 1 and Task 2 data sets (due to repeated measures) and in Task 3 were replaced with the mean of the same trial for the other 4 subjects in the same age/gender group.

Task 1

Errors

Five error trials occurred in Task 1. These trials were removed from the data set.

Subject Group	Response Time (ms)	Comments
YM	1731	Invalid response to the slide.
YM	1095	Invalid response to the slide.
OF	22644	Subject did not notice that a map had come up.
OF	19166	Subject did not notice that a map had come up.
OM	22018	Subject did not notice that a map had come up.

Outliers

The histogram of all response times was observed after the five error trials were replaced. A large gap in response times occurred past 12,500 ms. So, response times greater than this were identified as potential outliers for Task 1.

The next step was to compare the response time for a specific data point to the repeated trials within the same subject. If the response time for that data point was more than three standard deviations away from the mean of the repeated trials, the data point was considered an outlier and was removed from the data set. A total of 11 outliers were removed from the data set for Task 1.

Subject Group	Response Time (ms)	Mean (repeated)	Mean+3*SD (repeated)	Remove?
OF	15355	2099	2605	YES
OM	14188	8659	13812	YES
OM	20844	5770	9497	YES
OM	15345	2041	3852	YES
OM	15853	4868	11836	YES
OM	25000	4304	12399	YES
OM	14281	4304	12399	YES
OF	25000	2943	6770	YES
OF	13441	6148	6347	YES
OF	25000	6148	6347	YES
OF	23425	4969	14527	YES

Task 2

Errors

One error trial was removed from the data set. This trial was an error because the slide was missing from the carousel. The original response time for the trial was 22,854 ms.

Outliers

After the one error trial was removed from the data set, the outlier analysis was performed. Trials were identified as potential outliers if they were more than three standard deviations away from the mean for a particular number of streets. These individual trials were finally considered outliers if the response time was greater than three standard deviations away from the mean for that particular subject and subject group.

Only one trial was removed as an outlier for Task 2. The response time for this trial was 25,000 ms, the maximum time allowed.

Task 3

Errors

Six errors occurred in Task 3. The mean of the same trial for the other four subjects within the same age/gender group was used as the replacement time.

Subject Group	Response Time (ms)	Replacement Time (ms)	Comments
OM	5134	3869	Driving simulation ended.
OM	5815	3668	Driving simulation ended.
OM	22753	6196	Driving simulation ended.
OM	8328	5846	Driving simulation ended.
OM	21087	9762	Subject did not notice that map had come up.
OF	72	6822	Impossibly low response time.

Outliers

After the six error trials were replaced, the oulier analysis was performed. Trials were identified as potential outliers if they were more than three standard deviations away from the mean for a particular number of streets. These individual trials were finally considered outliers if the response time was greater than three standard deviations away from the mean for that particular subject and subject group. A total of 14 outliers were replaced for Task 3.

Streets	Mean	Standard Deviation (SD)	Mean + 3*SD
6	2945	1418	7199
12	4106	2060	10286
24	5935	3007	14956

Streets	Subject Group	Response Time (ms)	Mean + 3*SD (Subject)	Mean + 3*SD (Subject Group)	Replacement Time (ms)
6	YF	10526	6508	5358	4588
6	YM	11636	6620	5604	2637
6	YF	8708	6128	5358	2205
6	OM	13479	11222	8220	2993
6	OM	9072	7462	8220	5932
6	OF	11530	10417	8001	2238
12	YF	12604	8261	6987	3232
12	OM	16378	15848	12887	8196
12	OM	18671	13386	12887	4743
12	OF	13606	12862	10019	3457
12	OF	11075	10568	10019	3979
24	YF	25000	16599	12638	8204
24	OM	19504	19269	18016	7327
24	OF	16559	14592	13299	4698

APPENDIX O – Task 1 Error ANOVA Table

Source	df	Sum of Squares	Mean Square	F-value	p-value
Age	1	2.52E3	2.52E3	3.718	.0718
Gender	1	186.05	186.05	0.274	.6078
Age * Gender	1	369.8	369.8	0.545	.4711
Subject(Group)	16	1.09E4	6.79E2		
Point Size	1	7.77E2	7.77E2	2.450	.1371
Point Size * Age	1	1.27E2	1.27E2	0.399	.5364
Point Size * Gender	1	64.80	64.80	0.204	.6574
Point Size * Age * Gender	1	6.05	6.05	0.019	.8919
Point Size * Subject(Group)	16	5.08E3	3.17E2		
Streets	2	7.07E3	3.54E3	29.936	<.0001
Streets * Age	2	2.3E2	1.15E2	0.972	.3892
Streets * Gender	2	41.48	20.74	0.176	.8398
Streets * Age * Gender	2	41.48	20.74	0.176	.8398
Streets * Subject(Group)	32	3.78E3	118.15		
Street Layout	1	2.41E3	2.41E3	17.458	.0007
Street Layout * Age	1	1.55E2	1.55E2	1.125	.3047
Street Layout * Gender	1	1.12E2	1.12E2	0.813	.3806
Street Layout * Age * Gender	1	6.05	6.05	0.044	.8367
Street Layout * Subject(Group)	16	2.2E3	1.38E2		
Orientation	2	2.22E4	1.11E4	30.299	<.0001
Orientation * Age	2	2.79E2	139.61	0.381	.6864
Orientation * Gender	2	6.47E2	3.23E2	0.882	.4238
Orientation * Age * Gender	2	1.91E3	9.56E2	2.606	.0894
Orientation * Subject(Group)	32	1.17E4	3.67E2		
Point Size * Streets	2	5.5E2	2.75E2	1.337	.2768
Point Size * Streets * Age	2	9.62E2	4.81E2	2.341	.1125
Point Size * Streets * Gender	2	4.85E2	2.42E2	1.179	.3205
Point Size * Streets * Age * Gender	2	5.55E2	2.77E2	1.350	.2737
Point Size * Streets * Subject(Group)	32	6.58E3	2.06E2		
Point Size * Street Layout	1	1.58E3	1.58E3	17.049	.0008
Point Size * Street Layout * Age	1	18.69	18.69	0.202	.6592
Point Size * Street Layout * Gender	1	186.05	186.05	2.010	.1755
Point Size * Street Layout * Age * Gender	1	5.27E2	5.27E2	5.693	.0297
Pt Size * Street Layout * Subject(Group)	16	1.48E3	92.57		
Point Size * Orientation	2	1.22E3	6.1E2	4.944	.0135
Point Size * Orientation * Age	2	34.64	17.32	0.140	.8697
Point Size * Orientation * Gender	2	56.41	28.20	0.228	.7971
Point Size * Orientation * Age * Gender	2	5.55E2	2.78E2	2.248	.1220
Point Size * Orientation * Subject(Group)	32	3.95E3	1.23E2		
Streets * Street Layout	2	4.55E3	2.28E3	20.279	<.0001
Streets * Street Layout * Age	2	2.94E2	1.47E2	1.309	.2842
Streets * Street Layout * Gender	2	2.79E2	1.4E2	1.244	.3018

Streets * Street Layout * Age * Gender	2	4.57E2	2.29E2	2.037	.1470
Streets * Street Layout * Subject(Group)	32	3.59E3	1.12E2		
Streets * Orientation	4	1.43E4	3.57E3	26.968	<.0001
Streets * Orientation * Age	4	9.03E2	2.26E2	1.707	.1593
Streets * Orientation * Gender	4	1.32E2	33.08	0.250	.9085
Streets * Orientation * Age * Gender	4	86.492	21.62	0.164	.9561
Streets * Orientation * Subject(Group)	64	8.46E3	132.22		
Street Layout * Orientation	2	2.85E3	1.43E3	14.225	<.0001
Street Layout * Orientation * Age	2	2.04E2	1.02E2	1.018	.3727
Street Layout * Orientation * Gender	2	1.01E2	50.61	0.505	.6083
Street Layout * Orientation * Age * Gender	2	18.86	9.43	0.094	.9105
Street Layout * Orient. * Subject(Group)	32	3.21E3	100.25		
Point Size * Streets * Street Layout	2	4.36E2	2.18E2	1.463	.2466
Point Size * Streets * Street Layout * Age	2	4.89E2	2.44E2	1.642	.2095
Pt Size * Streets * Street Layout * Gender	2	42.31	21.154	0.142	.8681
Point Size * Streets * Grid * Age * Gender	2	2.94E2	1.47E2	0.988	.3832
Pt Size * Streets * Grid * Subject(Group)	32	4.76E3	148.85		
Point Size * Streets * Orientation	4	3.27E2	81.662	0.419	.7943
Point Size * Streets * Orientation * Age	4	1.94E3	4.86E2	2.493	.0517
Point Size * Streets * Orientation * Gender	4	8.29E2	2.07E2	1.064	.3817
Pt Size * Streets * Orient. * Age * Gender	4	5.22E2	1.3E2	0.670	.6155
Pt Size * Sts * Orient. * Subject(Group)	64	1.25E4	1.95E2		
Point Size * Street Layout * Orientation	2	1.12E3	5.62E2	5.137	.0116
Pt Size * Street Layout * Orientation * Age	2	9.5E2	4.75E2	4.343	.0214
Pt Size * Street Layout * Orient. * Gender	2	18.9	9.43	0.086	.9176
Point Size * Grid * Orient. * Age * Gender	2	72.9	36.44	0.333	.7192
Pt Size * Grid * Orient. * Subject(Group)	32	3.5E3	1.09E2		
Streets * Street Layout * Orientation	4	3.17E3	7.92E2	6.252	.0003
Streets * Street Layout * Orientation * Age	4	2.26E3	5.66E2	4.468	.0030
Sts * Street Layout * Orientation * Gender	4	3.68E2	92.12	0.728	.5764
Streets * Grid * Orient. * Age * Gender	4	4.09E2	102.19	0.807	.5252
Streets * Grid * Orient. * Subject(Group)	64	8.1E3	1.27E2		

APPENDIX P – Task 1 Response-Time ANOVA Table

Source	df	Sum of Squares	Mean Square	F-value	p-value
Age	1	5.449E7	5.449E7	8.941	.0087
Gender	1	1.126E7	1.126E7	1.848	.1929
Age * Gender	1	2.44E7	2.44E7	4.004	.0627
Subject(Group)	16	9.75E7	6.094E6		
Point Size	1	2.264E6	2.264E6	1.416	.2514
Point Size * Age	1	2.525E5	2.525E5	0.158	.6964
Point Size * Gender	1	7.871E5	7.871E5	0.492	.4930
Point Size * Age * Gender	1	2.927E5	2.927E5	0.183	.6745
Point Size * Subject(Group)	16	2.558E7	1.599E6		
Streets	2	3.992E7	1.996E7	65.877	<.0001
Streets * Age	2	3.226E6	1.613E6	5.325	.0101
Streets * Gender	2	3.151E6	1.576E6	5.201	.0111
Streets * Age * Gender	2	5.628E5	2.814E5	0.929	.4054
Streets * Subject(Group)	32	9.695E6	3.03E5		
Street Layout	1	1.21E3	1.21E3	0.003	.9554
Street Layout * Age	1	2.39E5	2.39E5	0.638	.4360
Street Layout * Gender	1	1.36E5	1.36E5	0.362	.5558
Street Layout * Age * Gender	1	3.583E5	3.583E5	0.956	.3429
Street Layout * Subject(Group)	16	6E6	3.75E5		
Orientation	2	5.924E7	2.962E7	77.341	<.0001
Orientation * Age	2	1.179E7	5.895E6	15.393	<.0001
Orientation * Gender	2	6.78E5	3.39E5	0.885	.4225
Orientation * Age * Gender	2	5.192E5	2.596E5	0.678	.5148
Orientation * Subject(Group)	32	1.225E7	3.83E5		
Point Size * Streets	2	4.375E5	2.187E5	0.693	.5074
Point Size * Streets * Age	2	1.452E5	7.259E4	0.230	.7958
Point Size * Streets * Gender	2	5.704E5	2.852E5	0.904	.4152
Point Size * Streets * Age * Gender	2	6.939E5	3.469E5	1.099	.3454
Point Size * Streets * Subject(Group)	32	1.01E7	3.156E5		
Point Size * Street Layout	1	1.298E6	1.298E6	6.019	.0260
Point Size * Street Layout * Age	1	3.22E5	3.22E5	1.491	.2397
Point Size * Street Layout * Gender	1	1.73E3	1.73E3	0.008	.9297
Point Size * Street Layout * Age * Gender	1	5.398E5	5.398E5	2.503	.1332
Pt Size * Street Layout * Subject(Group)	16	3.45E6	2.156E5		
Point Size * Orientation	2	3.418E6	1.709E6	6.694	.0037
Point Size * Orientation * Age	2	2.12E6	1.06E6	4.155	.0249
Point Size * Orientation * Gender	2	5.039E4	2.519E4	0.099	.9063
Point Size * Orientation * Age * Gender	2	1.179E6	5.895E5	2.309	.1157
Point Size * Orientation * Subject(Group)	32	8.17E6	2.553E5		
Streets * Street Layout	2	2.427E6	1.213E6	3.154	.0562
Streets * Street Layout * Age	2	2.26E3	1.13E3	0.003	.9971
Streets * Street Layout * Gender	2	2.954E5	1.477E5	0.384	.6843

Streets * Street Layout * Age * Gender	2	1.549E6	7.747E5	2.014	.1500
Streets * Street Layout * Subject(Group)	32	1.231E7	3.847E5		
Streets * Orientation	4	2.587E7	6.467E6	24.444	<.0001
Streets * Orientation * Age	4	2.685E6	6.712E5	2.537	.0485
Streets * Orientation * Gender	4	3.971E6	9.928E5	3.752	.0084
Streets * Orientation * Age * Gender	4	1.381E6	3.453E5	1.305	.2776
Streets * Orientation * Subject(Group)	64	1.693E7	2.646E5		
Street Layout * Orientation	2	9.48E5	4.74E5	1.488	.2410
Street Layout * Orientation * Age	2	3.875E5	1.937E5	0.608	.5504
Street Layout * Orientation * Gender	2	1.991E5	9.957E4	0.313	.7337
Street Layout * Orient. * Age * Gender	2	1.505E6	7.527E5	2.363	.1103
Street Layout * Orient. * Subject(Group)	32	1.019E7	3.185E5		
Point Size * Streets * Street Layout	2	3.938E5	1.969E5	0.621	.5439
Point Size * Streets * Street Layout * Age	2	1.302E5	6.511E4	0.205	.8155
Pt Size * Streets * Street Layout * Gender	2	1.246E5	6.228E4	0.196	.8227
Pt Size * Streets * Grid * Age * Gender	2	2.332E5	1.166E5	0.368	.6952
Pt Size * Streets * Grid * Subject(Group)	32	1.015E7	3.172E5		
Point Size * Streets * Orientation	4	9.686E5	2.422E5	1.053	.3869
Point Size * Streets * Orientation * Age	4	1.907E5	4.77E4	0.207	.9334
Point Size * Streets * Orient. * Gender	4	5.415E5	1.354E5	0.589	.6719
Pt Size * Streets * Orient. * Age * Gender	4	1.349E6	3.372E5	1.467	.2227
Pt Size * Sts * Orient. * Subject(Group)	64	1.471E7	2.299E5		
Point Size * Street Layout * Orientation	2	1.368E6	6.839E5	3.814	.0327
Pt Size * Street Layout * Orient. * Age	2	9.49E5	4.74E5	2.645	.0865
Pt Size * Street Layout * Orient. * Gender	2	1.93E6	9.636E5	5.375	.0097
Point Size * Grid * Orient. * Age * Gender	2	6.485E4	3.243E4	0.181	.8354
Pt Size * Grid * Orient. * Subject(Group)	32	5.74E6	1.793E5		
Streets * Street Layout * Orientation	4	2.556E6	6.391E5	1.744	.1512
Sts * Street Layout * Orientation * Age	4	1.225E6	3.064E5	0.836	.5073
Sts * Street Layout * Orient. * Gender	4	5.246E5	1.312E5	0.358	.8376
Streets * Grid * Orient. * Age * Gender	4	1.191E6	2.978E5	0.813	.5218
Streets * Grid * Orient. * Subject(Group)	64	2.345E7	3.665E5		

APPENDIX Q - Task 2 Error ANOVA Table

Source	df	Sum of Squares	Mean Square	F-value	p-value
Age	1	4878.02	4878.02	4.243	.0561
Gender	1	2356.27	2356.27	2.049	.1715
Age * Gender	1	1926.67	1926.67	1.676	.2139
Subject(Group)	16	18396.03	1149.75		
Point Size	1	2774.40	2774.40	7.679	.0136
Point Size * Age	1	9.60	9.60	.027	.8726
Point Size * Gender	1	98.82	98.82	.274	.6081
Point Size * Age * Gender	1	10.42	10.42	.029	.8673
Point Size * Subject(Group)	16	5780.43	361.28		
Streets	2	10117.11	5058.55	24.391	<.0001
Streets * Age	2	988.11	494.05	2.382	.1085
Streets * Gender	2	399.61	199.80	.963	.3924
Streets * Age * Gender	2	240.61	120.30	.580	.5656
Streets * Subject(Group)	32	6636.57	207.39		
Street Layout	1	96.27	96.27	.141	.7123
Street Layout * Age	1	135.00	135.00	.198	.6626
Street Layout * Gender	1	608.02	608.02	.890	.3594
Street Layout * Age * Gender	1	421.35	421.35	.617	.4437
Street Layout * Subject(Group)	16	10927.70	682.98		
Point Size * Streets	2	2388.23	1194.11	5.800	.0071
Point Size * Streets * Age	2	86.03	43.01	.209	.8125
Point Size * Streets * Gender	2	261.16	130.58	.634	.5368
Point Size * Streets * Age * Gender	2	335.16	167.58	.814	.4520
Point Size * Streets * Subject(Group)	32	6587.77	205.87		
Point Size * Street Layout	1	30.82	30.82	.294	.5954
Point Size * Street Layout * Age	1	93.75	93.75	.893	.3587
Point Size * Street Layout * Gender	1	9.60	9.60	.091	.7662
Pt Size * Street Layout * Age * Gender	1	56.07	56.07	.534	.4754
Pt Size * St. Layout * Subject(Group)	16	1679.43	104.97		
Streets * Street Layout	2	10062.66	5031.33	13.963	<.0001
Streets * Street Layout * Age	2	3883.13	1941.56	5.388	.0096
Streets * Street Layout * Gender	2	766.46	383.23	1.064	.3571
Streets * Street Layout * Age * Gender	2	511.73	255.86	.710	.4992
Sts * Street Layout * Subject(Group)	32	11530.70	360.33		
Point Size * Streets * Street Layout	2	988.11	494.05	3.130	.0574
Pt Size * Streets * Street Layout * Age	2	90.98	45.49	.288	.7516
Point Size * Streets * Grid * Gender	2	140.48	70.24	.445	.6448
Pt Size * Streets * Grid * Age * Gender	2	207.01	103.50	.656	.5259
Pt Size * Sts * Grid * Subject(Group)	32	5051.77	157.87		

APPENDIX R – Task 2 Response-Time ANOVA Table

Source	df	Sum of Squares	Mean Square	F-value	p-value
Age	1	1.085E7	1.085E7	4.158	.0583
Gender	1	1.69E6	1.69E6	0.647	.4329
Age * Gender	1	7.186E6	7.186E6	2.753	.1165
Subject(Group)	16	4.176E7	2.61E6		
Point Size	1	1.902E6	1.902E6	3.503	.0797
Point Size * Age	1	7.56E2	7.56E2	0.001	.9707
Point Size * Gender	1	1.496E5	1.496E5	0.276	.6069
Point Size * Age * Gender	1	3.2E5	3.2E5	0.589	.4540
Point Size * Subject(Group)	16	8.688E6	5.43E5		
Streets	2	9.979E6	4.99E6	15.978	<.0001
Streets * Age	2	1.106E5	5.532E4	0.177	.8385
Streets * Gender	2	9.229E5	4.614E5	1.478	.2433
Streets * Age * Gender	2	2.622E5	1.311E5	0.420	.6607
Streets * Subject(Group)	32	9.993E6	3.123E5		
Street Layout	1	7.5E6	7.5E6	14.206	.0017
Street Layout * Age	1	2.67E6	2.67E6	5.058	.0389
Street Layout * Gender	1	3.968E4	3.968E4	0.075	.7875
Street Layout * Age * Gender	1	1.545E6	1.545E6	2.925	.1065
Street Layout * Subject(Group)	16	8.449E6	5.281E5		
Point Size * Streets	2	2.324E6	1.162E6	4.586	.0177
Point Size * Streets * Age	2	1.655E5	8.274E4	0.327	.7237
Point Size * Streets * Gender	2	3.083E4	1.542E4	0.061	.9411
Point Size * Streets * Age * Gender	2	2.121E5	1.06E5	0.419	.6615
Point Size * Streets * Subject(Group)	32	8.106E6	2.533E5		
Point Size * Street Layout	1	3.374E6	3.374E6	10.952	.0044
Point Size * Street Layout * Age	1	3.221E5	3.221E5	1.046	.3218
Point Size * Street Layout * Gender	1	3.8E4	3.8E4	0.123	.7302
Pt Size * Street Layout * Age * Gender	1	1.179E6	1.179E6	3.828	.0681
Pt Size * St. Layout * Subject(Group)	16	4.929E6	3.081E5		
Streets * Street Layout	2	3.447E6	1.724E6	13.063	<.0001
Streets * Street Layout * Age	2	1.378E5	6.892E4	0.522	.5981
Streets * Street Layout * Gender	2	3.175E5	1.588E5	1.203	.3135
Streets * Street Layout * Age * Gender	2	5.325E5	2.662E5	2.018	.1495
Sts * Street Layout * Subject(Group)	32	4.223E6	1.32E5		
Point Size * Streets * Street Layout	2	9.378E5	4.689E5	1.576	.2223
Pt Size * Streets * Street Layout * Age	2	3.043E5	1.522E5	0.512	.6044
Point Size * Streets * Grid * Gender	2	2.882E5	1.441E5	0.484	.6205
Pt Size * Streets * Grid * Age * Gender	2	1.514E5	7.571E4	0.255	.7768
Pt Size * Sts * Grid * Subject(Group)	32	9.518E6	2.975E5		

APPENDIX S – Task 3 Error ANOVA Table

Source	df	Sum of Squares	Mean Square	F-value	p-value
Age	1	1.46E5	1.5E5	32.361	<.0001
Gender	1	3.36E2	3.4E2	0.075	.7882
Age * Gender	1	225	225	0.050	.8259
Subject(Group)	16	7.2E4	4.5E3		
Point Size	1	3025	3025	2.578	.1279
Point Size * Age	1	1225	1225	1.044	.3221
Point Size * Gender	1	3.36E2	3.4E2	0.286	.5999
Point Size * Age * Gender	1	4.69E2	4.7E2	0.400	.5360
Point Size * Subject(Group)	16	1.88E4	1.2E3		
Streets	2	1.54E5	7.7E4	58.755	<.0001
Streets * Age	2	3.76E4	1.9E4	14.356	<.0001
Streets * Gender	2	4.01E3	2E3	1.529	.2321
Streets * Age * Gender	2	3.02E3	1.5E3	1.152	.3289
Streets * Subject(Group)	32	4.19E4	1.3E3		
Orientation	2	3.27E3	1.6E3	2.005	.1512
Orientation * Age	2	2.27E3	1.1E3	1.392	.2631
Orientation * Gender	2	4.39E2	2.2E2	0.269	.7659
Orientation * Age * Gender	2	3350	1675	2.053	.1450
Orientation * Subject(Group)	32	2.61E4	8.2E2		
Street Layout	1	1.4E4	1.4E4	16.235	.0010
Street Layout * Age	1	25.0	25.0	0.029	.8669
Street Layout * Gender	1	2.34E3	2.3E3	2.709	.1193
Street Layout * Age * Gender	1	3.36E2	3.4E2	0.390	.5413
Street Layout * Subject(Group)	16	13800	862.5		
Location	4	1.84E5	4.6E4	27.782	<.0001
Location * Age	4	3.78E4	9.5E3	5.697	.0005
Location * Gender	4	1.37E3	3.4E2	0.207	.9338
Location * Age * Gender	4	2.43E3	6.1E2	0.366	.8321
Location * Subject(Group)	64	1.06E5	1.7E3		
Point Size * Streets	2	2850	1425	1.013	.3745
Point Size * Streets * Age	2	4.62E3	2.3E3	1.641	.2097
Point Size * Streets * Gender	2	2.57E3	1.3E3	0.914	.4111
Point Size * Streets * Age * Gender	2	2.94E3	1.5E3	1.044	.3636
Point Size * Streets * Subject(Group)	32	4.5E4	1.4E3		
Point Size * Orientation	2	5850	2925	3.691	.0361
Point Size * Orientation * Age	2	1.32E3	6.6E2	0.831	.4449
Point Size * Orientation * Gender	2	9.06E2	4.5E2	0.571	.5704
Point Size * Orientation * Age * Gender	2	2.24E3	1.1E3	1.413	.2582
Point Size * Orient. * Subject(Group)	32	2.54E4	7.9E2		
Point Size * Street Layout	1	3.8E3	3.8E3	6.098	.0252
Point Size * Street Layout * Age	1	3.8E3	3.8E3	6.098	.0252
Point Size * Street Layout * Gender	1	4.69E2	4.7E2	0.753	.3984

Pt Size * Street Layout * Age * Gender	1	2.778	2.778	0.004	.9476
Pt Size * St. Layout * Subject(Group)	16	9.98E3	6.2E2		
Point Size * Location	4	6.52E3	1.6E3	2.437	.0560
Point Size * Location * Age	4	1.71E3	4.3E2	0.638	.6373
Point Size * Location * Gender	4	3.48E3	8.7E2	1.303	.2785
Point Size * Location * Age * Gender	4	3.07E3	7.7E2	1.149	.3417
Point Size * Location * Subject(Group)	64	4.28E4	6.7E2		
Streets * Orientation	4	4.64E3	1.2E3	1.488	.2164
Streets * Orientation * Age	4	7.58E3	1.9E3	2.427	.0568
Streets * Orientation * Gender	4	1.1E4	2.8E3	3.537	.0114
Streets * Orientation * Age * Gender	4	2.33E3	5.8E2	0.747	.5634
Streets * Orientation * Subject(Group)	64	5E4	7.8E2		
Streets * Street Layout	2	7.06E2	3.5E2	0.383	.6848
Streets * Street Layout * Age	2	1.72E3	8.6E2	0.932	.4041
Streets * Street Layout * Gender	2	1.27E3	6.4E2	0.691	.5085
Streets * Street Layout * Age * Gender	2	8.39E2	4.2E2	0.456	.6382
Sts * Street Layout * Subject(Group)	32	2.95E4	9.2E2		
Streets * Location	8	8E4	1E4	9.003	<.0001
Streets * Location * Age	8	11700	1462.5	1.316	.2410
Streets * Location * Gender	8	5.08E3	6.3E2	0.571	.7998
Streets * Location * Age * Gender	8	1.11E4	1.4E3	1.251	.2748
Streets * Location * Subject(Group)	128	1.42E5	1.1E3		
Orientation * Street Layout	2	6.67E3	3.3E3	4.138	.0252
Orientation * Street Layout * Age	2	3.17E2	1.6E2	0.196	.8227
Orientation * Street Layout * Gender	2	8.39E2	4.2E2	0.520	.5993
Orient. * Street Layout * Age * Gender	2	38.889	19.444	0.024	.9762
Orient. * Street Layout * Subject(Group)	32	25800	806.25		
Orientation * Location	8	1.51E4	1.9E3	2.036	.0471
Orientation * Location * Age	8	1.59E4	2E3	2.133	.0371
Orientation * Location * Gender	8	4.64E3	5.8E2	0.624	.7560
Orientation * Location * Age * Gender	8	1.21E4	1.5E3	1.630	.1225
Orientation * Location * Subject(Group)	128	1.19E5	9.3E2		
Street Layout * Location	4	3.66E4	9.1E3	8.965	<.0001
Street Layout * Location * Age	4	5.18E3	1.3E3	1.270	.2911
Street Layout * Location * Gender	4	2.21E3	5.5E2	0.540	.7066
Street Layout * Location * Age * Gender	4	7150	1787.5	1.752	.1496
St. Layout * Location * Subject(Group)	64	6.53E4	1E3		

APPENDIX T – Task 3 Response-Time ANOVA Table

Source	df	Sum of Squares	Mean Square	F-value	p-value
Age	1	1.495E9	1.495E9	9.629	.0068
Gender	1	5.741E8	5.741E8	3.642	.0744
Age * Gender	1	2.263E8	2.263E8	1.428	.2496
Subject(Group)	16	2.51E9	1.569E8		
Point Size	1	1.274E8	1.274E8	25.256	.0001
Point Size * Age	1	5.878E7	5.878E7	11.761	.0034
Point Size * Gender	1	1.227E7	1.227E7	2.233	.1545
Point Size * Age * Gender	1	1.698E5	1.698E5	0.017	.8966
Point Size * Subject(Group)	16	8.448E7	5.28E6		
Streets	2	5.466E9	2.733E9	272.70	<.0001
Streets * Age	2	3.645E7	1.823E7	1.861	.1720
Streets * Gender	2	1.43E8	7.17E7	6.974	.0031
Streets * Age * Gender	2	3.868E7	1.934E7	1.837	.1757
Streets * Subject(Group)	32	3.261E8	1.019E7		
Orientation	2	9.529E6	4.765E6	1.328	.2792
Orientation * Age	2	1.312E6	6.562E5	0.133	.8757
Orientation * Gender	2	8.356E6	4.178E6	1.055	.3600
Orientation * Age * Gender	2	1.736E6	8.682E5	0.253	.7778
Orientation * Subject(Group)	32	1.169E8	3.654E6		
Street Layout	1	5.006E7	5.006E7	17.038	.0008
Street Layout * Age	1	7.395E6	7.395E6	2.241	.1538
Street Layout * Gender	1	1.16E5	1.16E5	0.017	.8974
Street Layout * Age * Gender	1	1.153E7	1.153E7	3.555	.0777
Street Layout * Subject(Group)	16	4.742E7	2.964E6		
Location	4	6.955E8	1.739E8	32.476	<.0001
Location * Age	4	5.392E7	1.348E7	2.376	.0612
Location * Gender	4	1.049E8	2.623E7	4.618	.0024
Location * Age * Gender	4	8.358E6	2.09E6	0.341	.8491
Location * Subject(Group)	64	3.46E8	5.406E6		
Point Size * Streets	2	2.721E7	1.36E7	4.586	.0177
Point Size * Streets * Age	2	2.708E7	1.354E7	4.580	.0178
Point Size * Streets * Gender	2	9.63E6	4.815E6	1.555	.2266
Point Size * Streets * Age * Gender	2	5.234E6	2.617E6	0.821	.4491
Point Size * Streets * Subject(Group)	32	1.008E8	3.151E6		
Point Size * Orientation	2	1.097E7	5.483E6	2.943	.0671
Point Size * Orientation * Age	2	5.078E6	2.539E6	1.182	.3196
Point Size * Orientation * Gender	2	5.938E5	2.969E5	0.200	.8201
Point Size * Orientation * Age * Gender	2	3.26E6	1.63E6	0.743	.4836
Point Size * Orient. * Subject(Group)	32	6.025E7	1.883E6		
Point Size * Street Layout	1	5.002E5	5.002E5	0.173	.6830
Point Size * Street Layout * Age	1	3.988E3	3.988E3	0.001	.9729
Point Size * Street Layout * Gender	1	1.451E4	1.451E4	0.001	.9956

Pt Size * Street Layout * Age * Gender	1	3.982E5	3.982E5	0.132	.7216
Pt Size * St. Layout * Subject(Group)	16	3.353E7	2.096E6		
Point Size * Location	4	2.904E7	7.259E6	2.673	.0398
Point Size * Location * Age	4	2.556E6	6.391E5	0.288	.8845
Point Size * Location * Gender	4	5.248E6	1.312E6	0.442	.7778
Point Size * Location * Age * Gender	4	1.554E6	3.885E5	0.151	.9620
Point Size * Location * Subject(Group)	64	1.857E8	2.901E6		
Streets * Orientation	4	2.401E6	6.002E5	0.283	.8877
Streets * Orientation * Age	4	5.857E6	1.464E6	0.964	.4335
Streets * Orientation * Gender	4	1.17E7	2.924E6	1.595	.1863
Streets * Orientation * Age * Gender	4	6.713E6	1.678E6	1.155	.3391
Streets * Orientation * Subject(Group)	64	1.061E8	1.659E6		
Streets * Street Layout	2	3.286E7	1.643E7	5.976	.0062
Streets * Street Layout * Age	2	2.227E6	1.113E6	0.424	.6582
Streets * Street Layout * Gender	2	2.186E6	1.093E6	0.419	.6609
Streets * Street Layout * Age * Gender	2	2.171E7	1.085E7	3.522	.0415
Sts * Street Layout * Subject(Group)	32	9.335E7	2.917E6		
Streets * Location	8	4.915E8	6.144E7	25.137	<.0001
Streets * Location * Age	8	5.613E7	7.017E6	2.600	.0114
Streets * Location * Gender	8	4.284E7	5.355E6	2.096	.0407
Streets * Location * Age * Gender	8	2.297E7	2.871E6	1.087	.3762
Streets * Location * Subject(Group)	128	3.183E8	2.487E6		
Orientation * Street Layout	2	2.397E7	1.199E7	4.285	.0224
Orientation * Street Layout * Age	2	5.147E5	2.573E5	0.113	.8937
Orientation * Street Layout * Gender	2	5.133E6	2.566E6	0.850	.4370
Orient. * Street Layout * Age * Gender	2	2.81E6	1.405E6	0.477	.6250
Orient. * Street Layout * Subject(Group)	32	8.465E7	2.645E6		
Orientation * Location	8	5.941E7	7.427E6	2.975	.0043
Orientation * Location * Age	8	3.284E7	4.105E6	1.596	.1321
Orientation * Location * Gender	8	4.735E7	5.918E6	2.360	.0211
Orientation * Location * Age * Gender	8	1.713E7	2.141E6	0.870	.5433
Orientation * Location * Subject(Group)	128	3.143E8	2.456E6		
Street Layout * Location	4	7.417E7	1.854E7	5.707	.0005
Street Layout * Location * Age	4	3.64E7	9.101E6	2.805	.0328
Street Layout * Location * Gender	4	1.855E7	4.637E6	1.480	.2186
Street Layout * Location * Age * Gender	4	1.465E7	3.663E6	1.168	.3335
St. Layout * Location * Subject(Group)	64	2.164E8	3.381E6		