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Technical Report UMTRI-98-7

November, 1998

Map Design: A Simulator Evaluation of the Factors Affecting the Time to Read Electronic Navigation Displays

Aaron Brooks and Paul Green

HUMAN FACTORS

UMTRI The University of Michigan Transportation Research Institute

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16. Abstract
This report concerns the second of four experiments examining the time to read electronic maps while driving. Twenty subjects (ages 18-30 and 65+, equal numbers of men and women) drove the UMTRI driving simulator while performing one of three tasks: (1) identify the street being driven, (2) find the name of a cross street ahead, and (3) locate a particular street. The screen was located 24.5 degrees below horizontal and 34 degrees right of center, with a viewing distance of about 76 cm.

Four factors were varied: (1) the number of streets displayed (12, 24, and 36), (2) the percentage of streets labeled (33, 66, and 100 percent), (3) the street name label size (10, 12, 14, 16, 18, 20 point), and (4) the display location (high and low on the center console).

Age had the largest effect on task response times, with older subjects taking 44 to 66 percent longer. Overall, the best text size was 14 point, although clutter effects were seen when maps had more than 16 labeled streets. For older subjects, the use of 10 point text yielded the longest response times (up to 40 percent longer than 14 point). Response times increased more with additional labeled streets than unlabeled ones.

Display location effects were only tested using task one (On-street). The high display location produced response times that were 10 percent faster than the low position.

17. Key Words
ITS, human factors, ergonomics, driving, electronic maps, display location, navigation systems, route guidance, simulator

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Map Design: A Simulator Evaluation of the Factors Affecting the Time to Read Electronic Navigation Displays

UMTRI Technical Report 98-7, November 1998
Aaron Brooks and Paul Green

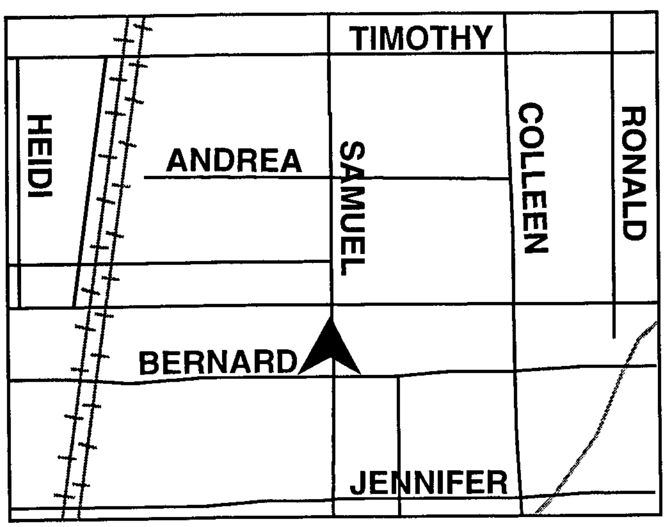
University of Michigan
Ann Arbor, Michigan, USA

1 ISSUES

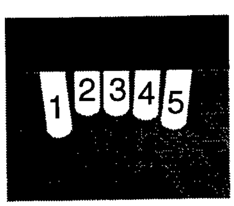
1. How many streets should appear on an in-vehicle navigation system?
2. How many streets should be labeled on an in-vehicle navigation system?
3. What size text should be used for the street labels?
4. What is the effect of display location on map-reading time?

2 MAP TASKS

Sample Map



Keypad Responses



Note:
only necessary response keys were visible during each task

<u>**Task 1 - On-Street**</u>
2 = male
3 = female

<u>**Task 2 - Cross Street**</u>
1 = not there
2 = male
3 = female
4 = not labeled

<u>**Task 3 - Where is?**</u>
1 = not there
2 = ahead 4 = left
3 = behind 5 = right

Task 1 **- On Street**

What street are you on?
Subject Finds: Samuel
Subject Responds: male (**2** key)

Task 2 **- Cross Street**

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

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

What is the 1st Cross Street?
Subject Finds: no name
Responds: not labeled (**4** key)

Task 3 **- Where is?**

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

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

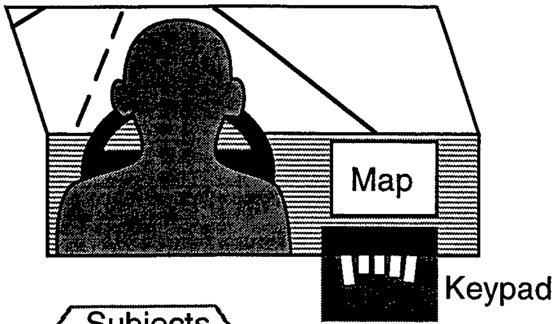
Where is Heidi?
Response: left (**4** key)

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

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

3 METHOD

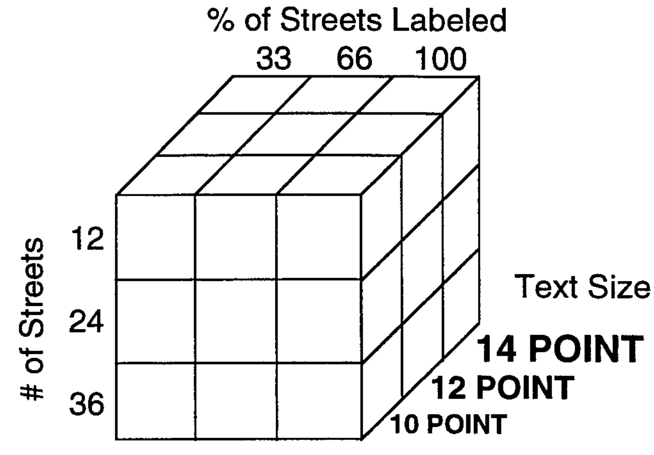
Simulator Driving Scenario



Subjects

	Young	Older
Men	**5**	**5**
Women	**5**	**5**

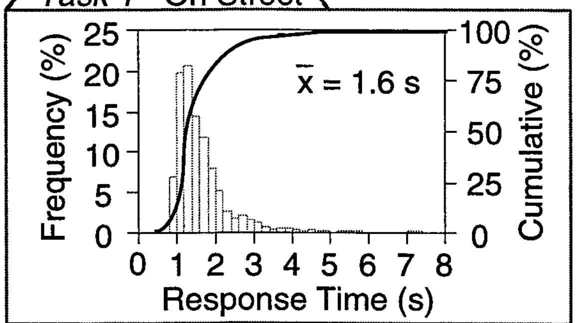
Main Test Conditons



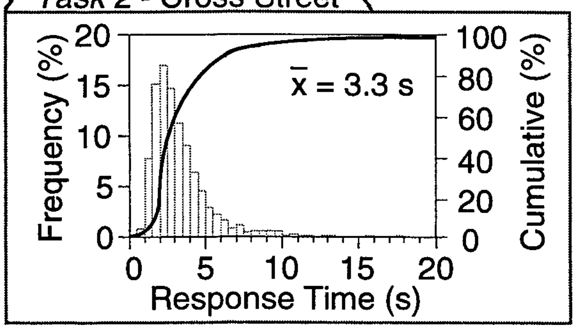
4 RESULTS & CONCLUSIONS

Response Times & Error Rates

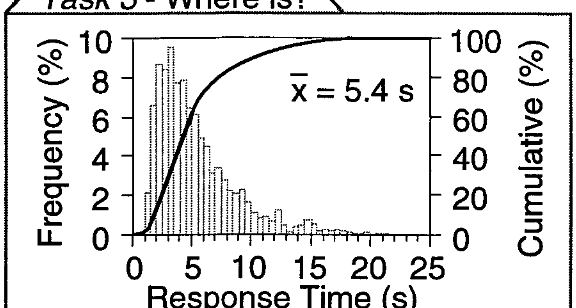
Task 1 - On Street



Task 2 - Cross Street

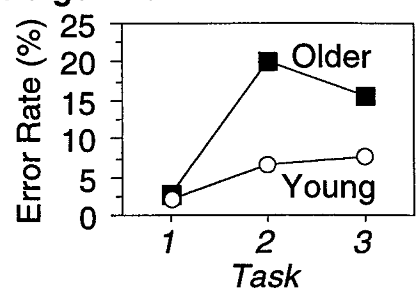


Task 3 - Where is?



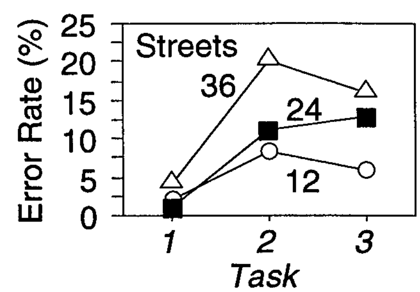
Task Differences

1. Age Effect



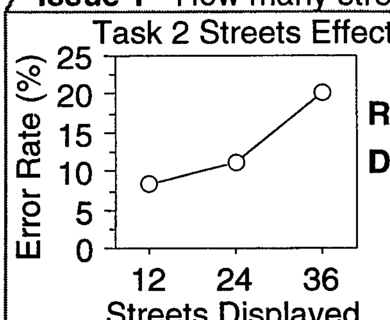
Large age differences

2. Number of Streets Effect



Task changes magnitude of streets effect

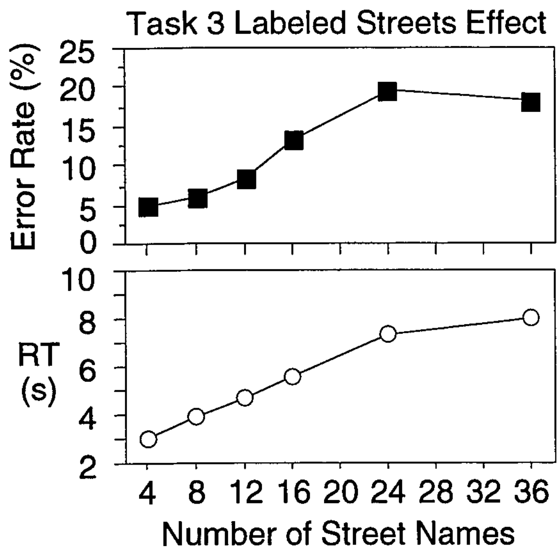
Issue 1 - How many streets to display?



Recommendation:

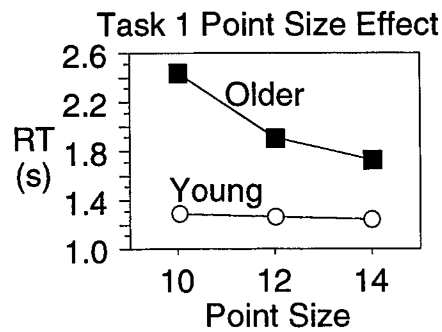
Display ≤ 24 Streets

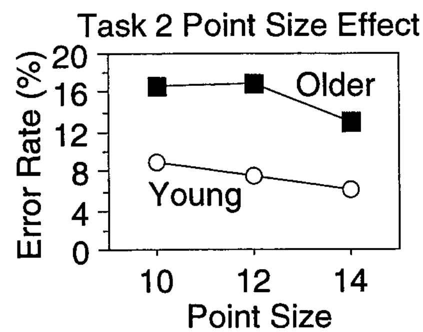
Issue 2 - How many streets to label?



Recommendation: Display ≤ 12 Labeled Streets

Issue 3 - What size text to use?

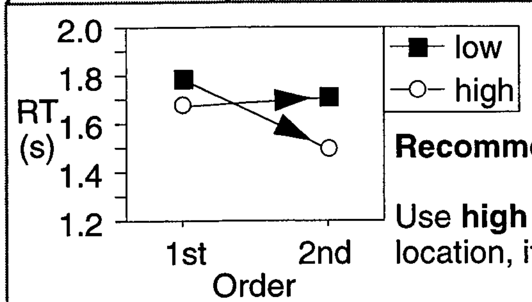




Recommendations:

1. Do **not** use < 12 point.
2. If map is not cluttered, **Use 14 point**

Issue 4 - Display Location effects



Recommendation:

Use **high** display location, if possible

Response Time Regression Equations (ms)

Task 1 - On-Street	$RT = 2563 + 381*(A) + 8*(S) - 94*(P) + 88*(12 - P)*(A) + 4*(A + 1)*(S - 12)*\left(\frac{1}{11-P}\right)$
Task 2 - Cross Street	$RT = 82 + 582*(A) + 61*(S) + 523*(X) + 19*(\text{Abs}\lvert X - 4\rvert)*(24 - S)$
Task 3 - Where is?	$RT = [\,2305 + 1137*(A) + 75*(S) - 81*(P) + 24*(PL) + 551*(L) + (S - 22)*(PL - 55)\,] * SR$

Terms for Regression Equations

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

PL = Percent of Streets Labeled ($1 \leq PL \leq 100$)

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

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

P = Point Size ($10 \leq P \leq 14$)

X = Target Cross Street ($X \geq 1$)

$L = \text{Target Location} \begin{cases} -1 \text{ for ahead} \\ 0 \text{ for behind, or not there} \\ +1 \text{ for side} \end{cases}$

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 5 reports summarized on the next page:

Green, P. (1998). 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. 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.

George, K., Hunter, D.R., Brooks, A., Lenneman, J., and Green, P. (1998). Preliminary Examinations of the Time to Read Electronic Maps: The Effects of Text and Graphic Characteristics, (Technical Report UMTRI-98-36) (in preparation).

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

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

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

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

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

Brooks, A., Nowakowski, C., and Green, P. (1998). Turn-by-Turn Displays versus Electronic Maps: An On-the-Road Comparison of Driver Glance Behavior, (Technical Report UMTRI-98-37).

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

TABLE OF CONTENTS

INTRODUCTION

Overview

Numerous features are being added to contemporary motor vehicles to improve the safety, efficiency, and pleasure of driving. Of those features, the navigation system is one of the most promising. Navigation systems are quite popular in Japan and have only recently begun to be mass marketed in the United States. These systems allow drivers to enter destinations via a variety of methods and provide turn-by-turn guidance (using special displays, maps, and voice).

To assure that such systems do not present undue risk to drivers, numerous safety and usability studies of navigation systems have been conducted (Dingus, Antin, Hulse, and Wierwille, 1989; Labiale, 1989; Dingus, Hulse, Krage, Szczublewski, and Berry, 1991; Green, 1992; Dingus, McGehee, Hulse, Jahns, Manakkal, Mollenhauer, and Fleischman, 1995; Green, Hoekstra, and Williams, 1993; Green, Williams, Hoekstra, George, and Wen, 1993; Schraagen, 1993; Ito and Miki, 1997; Katz, Fleming, Green, Hunter, and Damouth, 1997; Kimura, Marunaka, and Sugiura, 1997; Srinivasan and Jovanis, 1997; Manes, Green, and Hunter, 1998). These studies have addressed general issues such as the benefits of voice guidance, the benefits of point-on-a-map displays without guidance, comparisons of electronic navigation systems with paper maps, the time to enter destinations, etc. However, the number of studies that have addressed the next set of issues, optimization of the interface details, is somewhat more limited.

This project was conducted to help optimize the design of map displays. Although both turn and map displays appear in contemporary navigation systems, it was felt that map displays were in need of further development. Map displays are particularly popular in navigation systems used in Japan.

The first report of this project, an annotated bibliography of the research on reading electronic area maps (Green, 1998), indicated that the literature concerning such was very limited. Most studies concerned the assignment of colors to areas on a map (states or provinces) so that adjacent regions did not share the same color.

Four major experiments were performed in this project. The first 3 experiments, either performed in a driving simulator or on-the-road, used the same set of representative tasks. These tasks were selected because they are suggestive of the spectrum of tasks for which a map might be used. Further, they are interesting experimentally as they vary in complexity and completion time.

- Task 1 -- What street are you on?
- Task 2 -- What is the nth cross street ahead of you?
- Task 3 -- Where is street X on the map?

These tasks all involved some element of visual search, a class of tasks that has been well examined in the literature. In brief, search processes can be self-terminating or nonself-terminating. In a self-terminating search, items are examined in a specific order. Hence, the total search time is equal to a fixed time per item plus an added constant associated with response processes. Therefore, search time can be expressed as follows:

$$\text{Search Time} = c1 + (c2 * n)$$

where: c1, c2 = constants
n = # of terms in the list

In other cases, search times might be exponential (National Academy of Sciences, 1973). For example, in most searches of unstructured visual spaces, people look at the various locations in the space in a somewhat random manner, so the search process is Poisson. In those instances, the probability of locating a target by time t is as follows:

$$p_T = 1 - (1 - p_S)^{T/ts}$$

where: p_S = probability of finding the target in 1 fixation
t_S = average time for a fixation
p_T = probability of finding the target by time T

Several significant pilot studies were conducted as part of the first experiment. Those studies identified typical content of electronic maps (number of streets, street name length, etc. for the United States) and developed a task set that was representative of what drivers do.

The first major laboratory experiment, conducted in a driving simulator, examined the time to read electronic maps as a function of numerous map display factors (George, Hunter, Brooks, Lenneman, and Green, 1998). A total of 20 drivers, 10 young (18 to 30 years) and 10 older (65 and over) with equal numbers of men and women, operated a driving simulator while performing one of the tasks previously outlined.

Variables examined in the first experiment included: (1) the number of streets shown (6, 12, 18, 24, 36), (2) label size (12 and 18 point), (3) the street configuration (grid and nongrid), and (4) street label orientation (horizontal, vertical, and vertically stacked).

The results were that the response times increased as the number of streets shown increased. For the label size, the reading time for 18-point text was significantly slower (by 11 percent) than for 12-point text, especially with a large number of streets on the map. Large point sizes combined with many visible streets created a cluttered map, which dramatically increased the drivers' response times. Additionally, drivers were able to read the maps faster when the maps were based on a grid layout, rather than a less structured, more random arrangement (grid regularity facilitated search). Finally, the best label orientations were horizontal for horizontal streets and vertical for vertical streets, even though horizontal text is normally easier to read. The vertical text facilitated the association of each label with a particular line representing a street.

To establish how well the simulator data predicted real world use, an on-the-road study (Nowakowski and Green, 1998) was conducted in parallel with this laboratory study. The tasks used were the same as in the previous simulator studies (road driven, cross street, where is a particular street). Three factors were varied: (1) the number of streets displayed (12 and 24), (2) the street label size (10, 12, and 14 point), and (3) the time of day (day versus night driving). Sixteen drivers, 8 young (18 to 30 years) and 8 older (65 and over) with an equal number of men and women, drove a test vehicle on public roads.

The largest effect was age, which increased task response times by 40 to 80 percent. Each additional labeled street increased the response time by 7 to 140 ms depending on the task (up to 30 percent). Using 14-point text reduced response time by 200 ms (up to 10 percent). Further, average response times were within 15 percent of the means for the same tasks completed in the simulator (described in this report). The pattern of results (significant factors, their relative impact) were also similar, thus validating the simulator results.

Subjective ratings by the drivers revealed uneasiness about their ability to drive safely when the task required more than 5 seconds to complete. To avoid exceeding that duration, using 14-point text and no more than 12 labeled streets was recommended.

This experiment was conducted to fill additional gaps in the literature with regard to situations where only some of the streets on a map are labeled and to consider the impact of map-display location on reading time and errors. In addition, this experiment provided baseline data for the subsequent on-the-road experiment. For consistency, the tasks and simulator were the same as in previous experiments. Some conditions were also repeated to facilitate the linking of studies.

Issues

1. How many streets should be displayed; how many should be labeled?

The first laboratory experiment found increasing the number of street names on a map sharply increased the time to complete map-related tasks. However, every street on the map was labeled, which is not always the case for real maps. Accordingly, this experiment considered the next logical step, in which varying fractions of the streets (including all of them) were labeled.

2. What size text should be used?

The first experiment explored 2 levels of text point size, 12 and 18. Since every street was labeled in that experiment, 18 point cluttered the maps too quickly and could only be used with a maximum of 24 streets. Furthermore, 18 point was much larger than point sizes used in commercial navigation systems. Therefore, the lower end of the point-size spectrum (10, 12, and 14) was explored in this experiment. Also, the higher end of point sizes (16, 18, and 20) was explored, but with only 33 percent of the streets labeled.

The legibility of displayed letters depends upon their subtended visual angle at any viewing distance (Smith, 1979). Here, navigation maps will be shown on a 5-inch diagonal display located in the center console, about 30 inches (about 76 cm) from the drivers eye. For ease of application, the recommendations provided in this report will be given in point size. For other viewing distances, the appropriate point size should be computed given the visual angles used in this report. A detailed discussion of visual angle considerations appears in Nowakowski and Green (1998).

3. How does display location affect map reading?

The location of the display is an issue of major concern to vehicle designers and contention for prime locations (high in the center console) can be fierce. This experiment examined driver performance for 2 display locations, high and low on the center console.

TEST PLAN

Overview

The protocol for the experiment was identical to the previous experiment except that some factors differed. Subjects drove a simulated vehicle while responding to maps. The 3 independent tasks were: (1) identify the name of the street on which they were traveling, (2) identify a particular cross street, and (3) locate a particular street on the map. Keypress response times and errors were recorded by the computer. After the trial was complete, the projector displayed the next slide after a short delay.

Test Participants

Twenty licensed drivers participated in the experiment, 10 young (18 to 30 years, mean = 24) and 10 older (65 and over, mean = 69). Within each age group there were 5 men and 5 women. Subjects were recruited using lists from previous UMTRI studies and from personal contacts. All were paid $40 for their participation.

Corrected visual acuity, tested using a Stereo Optical Vision Tester, ranged from 20/13 to 20/25 (mean = 20/18) for young subjects and from 20/18 to 20/70 (mean = 20/34) for the older subjects. Corrective eyewear was worn by 9 of the 20 subjects.

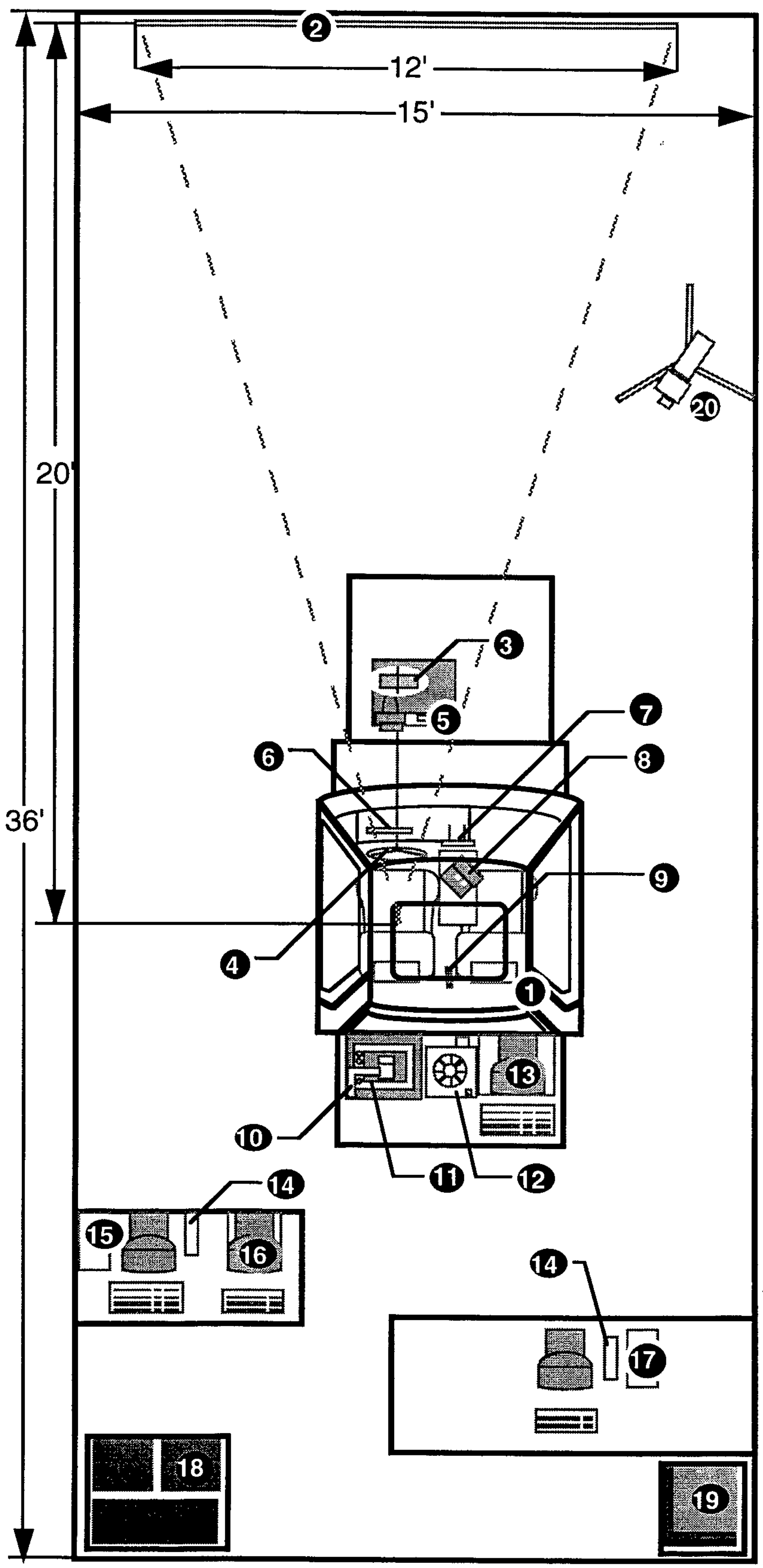
Subjects drove an average of 12,025 miles per year (ranging from 3,000 to 25,000) with little difference between the age and gender groups. Four older subjects reported using an in-vehicle navigation system during previous, unrelated UMTRI experiments. Subjects reported using a map an average of 3 to 4 times in the past six months. Young subjects reported the frequent use of a computer, while for most older subjects computer usage was infrequent or nonexistent.

Test Equipment and Materials

This experiment was conducted using the UMTRI Driver Interface Research Simulator, a low-cost driving simulator based on a network of Macintosh computers (MacAdam, Green, and Reed, 1993; Green and Olson, 1997; 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 driving landscape, providing a 30 degree field of view, was 20 feet (7.3 m) in front of the driver, essentially at optical infinity. The driving environment depicted was a two-lane winding road with no traffic ahead, stationary oncoming cars, traffic signs, and road edge posts.

The arrangement of all equipment in the laboratory used for the experiment is shown in Figure 1 on the following page.

Slides were presented by a Mast System 2 random-access slide projector. An IBM XT computer, with a timing board that measured responses to the nearest millisecond, was used to control the projector. Responses by the subject were obtained from a custom keyboard with 5 piano-like keys mounted above microswitches. The keyboard



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 1. Schematic view of laboratory set-up.

was designed so that the fingers of the subject would naturally rest directly over the keys. The keyboard was positioned to the right of the subject within easy reach on the center console.

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.

Test Activities and Their Sequence

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

Each session was separated into 2 practice tasks and 4 experimental tasks. (See Table 1.) 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. Before testing commenced, the subject was given a few minutes to practice driving and maintaining a constant speed.

Table 1. Summary and order of blocks for each session.

<table>
<tr><th>Block</th><th>Task description</th><th>Trials</th><th>Responses</th></tr>
<tr><td>Practice 1</td><td>Practice for Task 1</td><td>24</td><td rowspan="2">male or female</td></tr>
<tr><td>Task 1</td><td>What street are you on?</td><td>72</td></tr>
<tr><td>Task 2</td><td>What is the name of the nth cross street?</td><td>99</td><td>male, female, not there, or not labeled</td></tr>
<tr><td>Practice 2</td><td>Practice for Task 3</td><td>40</td><td rowspan="2">ahead, behind, left, right, or not there</td></tr>
<tr><td>Task 3</td><td>Where is the target street?</td><td>108</td></tr>
<tr><td>Task 4</td><td>Repeat of Task 1, with high and low display locations.</td><td>54</td><td>male or female</td></tr>
</table>

Each block began with approximately 30 seconds of driving to allow the subject to get up to speed and become comfortable. Once the subject was ready, the projector began to display slides on the screen that the subject responded to while driving. A 20 ms alert tone coincided with the appearance of each slide. The left hand was used to steer while the right hand pressed the appropriate key on the response board. Subsequently, the projector shutter closed and the projector advanced to the next slide. The intertrial interval (ITI) was uniformly distributed between 4 and 6.5 seconds.

Response times (in milliseconds) and errors were recorded for each trial. 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 blocks of trials, each subject completed a payment form and was then paid. The experiment took approximately 2 hours to complete.

Map Construction

All maps used in this experiment were based on 4 templates containing either 12, 24, or 36 streets. For each template, the 36-street maps were constructed first, then streets were deleted to create the 24- and 12-street maps. Streets were printed in 10-, 12-, or 14-point Helvetica (also 16, 18, and 20 point for Task 1), and were labeled along the street with common first names (unambiguously male or female). Table 2 summarizes the visual angles for the text (10, 12, and 14 point) displayed on the screen, which was 30 inches (76 cm) from the driver's eye. Pilot tests examined 8-point text also, but many older subjects were unable to read text of that size, so it was removed from the experiment. Names were obtained from a "baby book" (Evans, 1994) and ranged from 5 to 9 characters, lengths typical of U.S. street names. All maps were based on a grid design and contained 1 railroad and 1 river, characteristics typical of U.S. maps. Sample maps used in the experiment are located in Appendix D.

Table 2. Visual angles for text point sizes of 10, 12, and 14.

Point Size	Measurements (mm) Height (H)	Measurements (mm) Distance (D)	Visual Angle (minutes) [VA = 3438*(H/D)]
10	2.79	760	12.62
12	3.30	760	14.93
14	3.81	760	17.24

Task Descriptions

Practice 1: Keypad Practice (Male and Female)

The purpose of the first practice task was to teach subjects the association between keys and responses. Subjects were shown a slide (such as Figure 2) and asked to identify the gender of the name (index finger = male, middle finger = female). Subjects were instructed to respond as rapidly and accurately as possible.

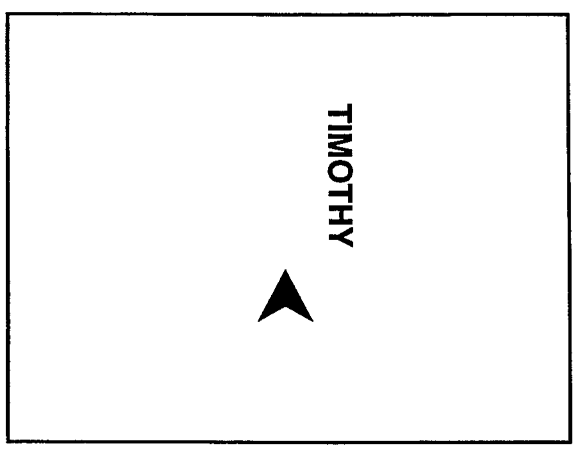


Figure 2. Practice 1 example slide.

Each combination of point size (10, 12, and 14), name orientation (horizontal or vertical), and name gender (male or female) were shown twice for a total of 24 trials. Design details can be found in Appendix E.

Task 1: What street are you on?

In Task 1, subjects were shown a total of 72 slides such as the one in Figure 3. The task was to find the vehicle icon (the arrowhead) showing the current location, then find the name of the street being driven, and finally press the key corresponding to the gender of the street name (left key = male, right key = female).

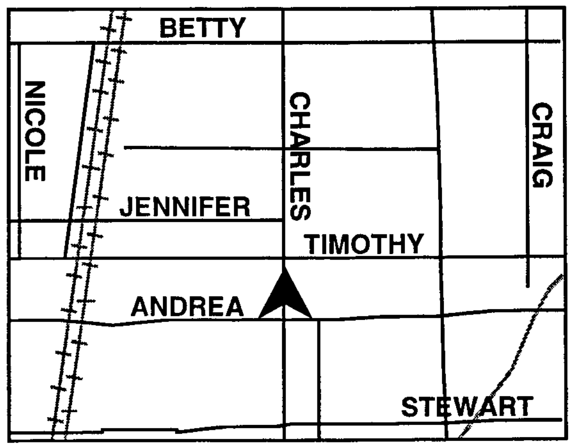


Figure 3. Task 1 example slide.

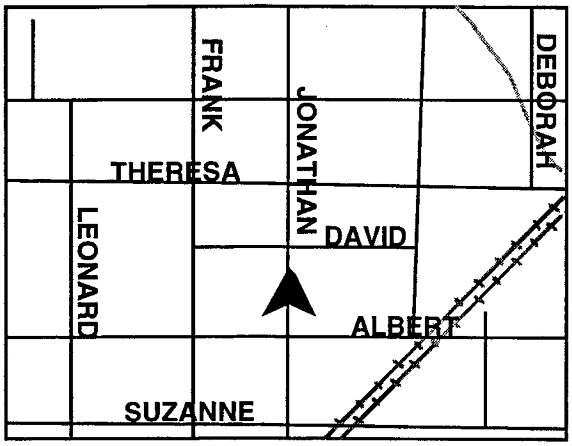
Each block consisted of 72 trials, of which 54 (=3 x 3 x 3 x 2) included all combinations of number of streets (12, 24, 36), point size (10, 12, 14), percentage of streets labeled (33, 66, 100), and response gender (male or female). The remaining 18 (=3 x 3 x 2) trials examined all combinations of alternate point sizes (16, 18, and 20) with number of streets (12, 24, 36) and response gender (male or female). On these 18 trials, map crowding allowed only 33 percent of the streets to be labeled. Details of the experimental design can be found in Appendix E.

Task 2: What is the nth cross street?

In addition to the "male" and "female" responses from Task 1, Task 2 included buttons for "not there" and "not labeled." Subjects did not receive practice in using them.

Subjects were shown a total of 99 slides such as the one in Figure 4. On each trial, the experimenter read a number (ranging from 1 to 8) 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 the second, etc.). Subjects identified the cross street as being "male," "female," "not labeled," or "not there" by pressing the appropriate key.

Each test block consisted of 99 trials, of which 54 (=3 x 3 x 3 x 2) included all combinations between number of streets (12, 24, 36), point size (10, 12, 14), percentage of streets labeled (33, 66, 100), and cross street named (1 or 3). The remaining 45 trials examined two additional levels of cross street named at each level of number of streets (2 and 4 at 12 streets, 4 and 6 at 24 streets, 6 and 8 at 36 streets). Table 3 shows the balancing scheme for this task.



Number read:	Subject thinks:	Subject responds:	Finger used to respond:
"1"	David	Male	Index
"2"	Theresa	Female	Middle
"3"	Not labeled	Not labeled	Ring
"4"	Not there	Not there	Thumb

Figure 4. Task 2 example.

Table 3. Cross streets named for each streets/percent labeled combination. All 3 levels of point size appear in each cell.

Streets	Percent	Cross street named					
	Labeled	1	2	3	4	6	8
12	33	√	√	√	√		
	66	√	√	√	√		
	100	√		√	√		
24	33	√		√	√	√	
	66	√		√	√	√	
	100	√		√		√	
36	33	√		√		√	√
	66	√		√		√	√
	100	√		√			√

Responses of "male" and "female" accounted for 63 trials (31 and 32, respectively), and the remaining 36 trials were "not labeled" and "not there" (18 trials each). All "not there" responses occurred only on the highest cross street named for each level of streets (i.e., "4" for 12 streets, "6" for 24 streets, and "8" for 36 streets), while the other responses were distributed over all cross streets. The experimental design for Task 2 can be found in Appendix E.

Practice 2: Keypad Practice (Location Keys)

The second practice task oriented subjects to the new responses of Task 3. The task was to give the location of a target street relative to the vehicle icon. The target street was indicated by a thick line (Figure 5) (no thick lines indicated "not there"). The 5 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. "Not there" was used when the target street was not on the map.

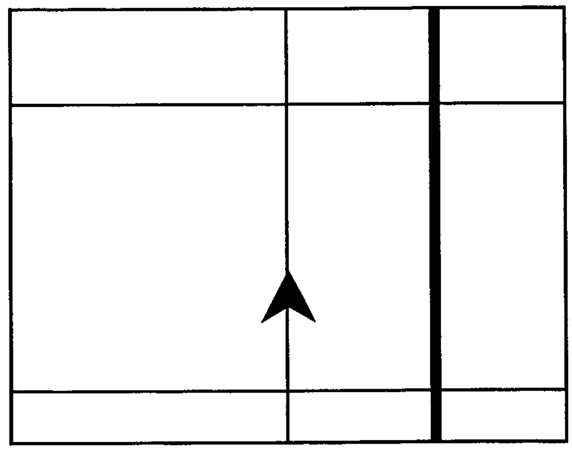
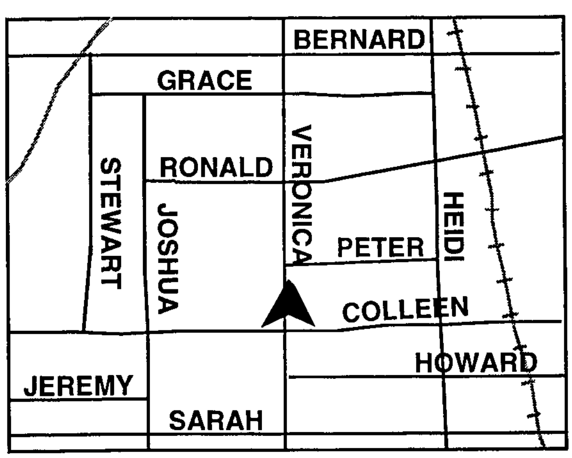


Figure 5. Practice 2 example slide. Correct response is "right."

The 5 street locations (ahead, behind, left, right, and not there) all had 2 different slides and were each shown 4 times for a total of 40 trials. The base template remained the same (3 streets and 1 arrow) for all 10 slides, with only the thick line changing location. Details of the experimental design are shown in Appendix E.

Task 3: Where is the target street?

In Task 3, subjects were shown a total of 108 slides such as the one in Figure 6. 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 that particular 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:
Grace	Ahead
Sarah	Behind
Stewart	Left
Heidi	Right
Charles	Not There

Figure 6. Task 3 example.

All combinations of number of streets (12, 24, 36), percentage of streets labeled (33, 66, 100), point size (10, 12, 14), and name location (ahead, behind, left/right, and not there) were shown once for a total of 108 trials. Left and right responses were combined and evenly balanced in one level, based on previous findings that response times and errors for these locations were not significantly different. The experimental design for Task 3 can be found in Appendix E.

Task 4: Display location

In Task 4, the task performed was the same as for Task 1 (What street you are on?) but in 2 equal sets of 27 trials. Each set of trials was devoted to a different display location; high in the center console as before, or 8 inches (20.3 cm) below, tilted upward. For a comfortably seated 6-foot-tall driver, the viewing distance from the eye to the center of the screen was 33.3 inches (84.6 cm). The screen was located 24.5 degrees below horizontal and 34 degrees to the right of center. Location order was blocked over age and balanced over gender. (See Table 4.)

Table 4. Number of subjects in each category.

Location	Young		Older	
Block Sequence	Men	Women	Men	Women
High, low (1)	3	2	2	3
Low, high (2)	2	3	3	2

In each set of 27 trials, all combinations of number of streets (12, 24 36), percentage of streets labeled (33, 66, 100), and point size (10, 12, 14) were shown once. Responses were nearly equal, with 14 male and 13 female responses. Details of the experimental design are located in Appendix E.

RESULTS

Data Reduction

Prior to data analysis, 37 of the 4,320 trials were replaced (Table 5) for a variety of reasons described below. (See Appendix F for further details.) In Task 1, replacements were other trials having the same map characteristics for the subject in question. In Tasks 2, 3, and 4, replacements were the cell means for those map characteristics in the same age/gender group (i.e., young women).

Table 5. Trials replaced.

Task	Task description	Outliers ($>3\sigma$)	Error trials	Total	Comments
1	What street are you on?	1	3	4	
2	What is the name of the nth cross street?	13	2	15	For ANOVA: 3 outliers and 0 error trials
3	Where is the target street?	9	2	11	
4	Repeat of Task 1, with high and low display locations.	1	6	7	
	Total	24	13	37	For ANOVA: 14 outliers and 11 error trials

The 24 outliers (mean ± 3*SD) were responses in excess of the 3σ time for both the subject and the age/gender group of the subject.

Due to procedural difficulties, 13 trials had to be replaced. Three of these instances were where the image was out of focus. Two were instances where driving was corrected during a trial and the subject did not look back to the screen. In 2 instances, the projector shutter did not open. There were single trial instances of an impossibly short response time (under 200 ms), a response key failure, an improperly positioned image, the subject forgetting the task instructions, and the subject not realizing that a slide was being shown. Finally, in Task 3 there was an instance where the experimenter said the wrong name to the subject.

After replacing all necessary data points, ANOVA was used to determine which factors significantly influenced ($p<.05$) subjects' time and accuracy of reading maps. Significance levels were generally much less than 0.01.

To simplify the analysis, the effect of the intertrial interval was checked prior to other analyses. The length of the intertrial interval (varying from 4.0 to 6.5 seconds) did not affect either response time or error rate for any of the tasks. Therefore, no mention is made of ITI from this point on.

Task 1: What street are you on?

The data analyzed by ANOVA for this task were all combinations of number of streets, percentage of streets labeled, response gender, and point size (10, 12, and 14 only).

Error Rate

Conditions leading to errors included pressing an incorrect button or failing to press any button within 25 seconds (the maximum response time) after the slide was shown. Out of 1,080 trials (20 subjects x 54 test trials per subject), 26 errors occurred (2.4 percent). This error rate was low because the name was always oriented in the same direction and in virtually the same position for every trial. As shown in Figure 7, subject errors appear randomly distributed over all age and gender groups.

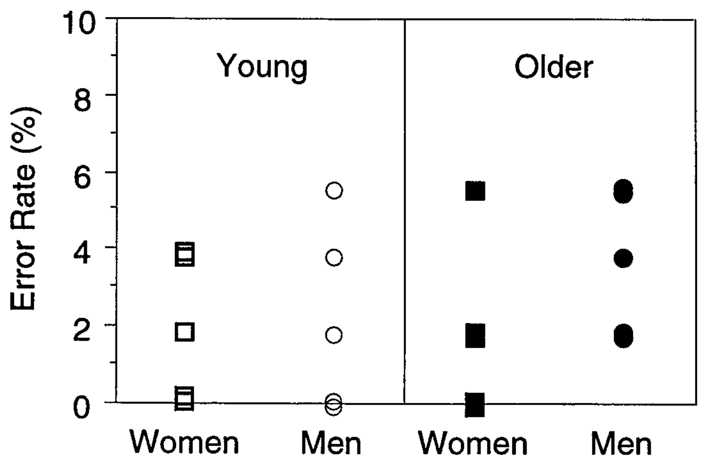


Figure 7. Error rates for all subjects, by age and gender.

Over one-third of the errors were simple name confusion. Names with similar spellings but different genders were often mistaken for each other. In responding to Denise, one subject said "It looked like Dennis" immediately following her error.

The remaining errors included accidental key presses (when the subject inadvertently touched the keypad, closing the switch contacts) and slips (when subjects knew which key to press, but pressed the wrong one regardless).

Response Time

The overall Task 1 mean response time was 1646 ms with a range of 803 to 7251 ms. (See Figure 8.) Response times under approximately 3000 ms accounted for 95 percent of the data. The response times were low, as expected, because Task 1 was a pure reading task, and the subject knew the general position and orientation of the target name.

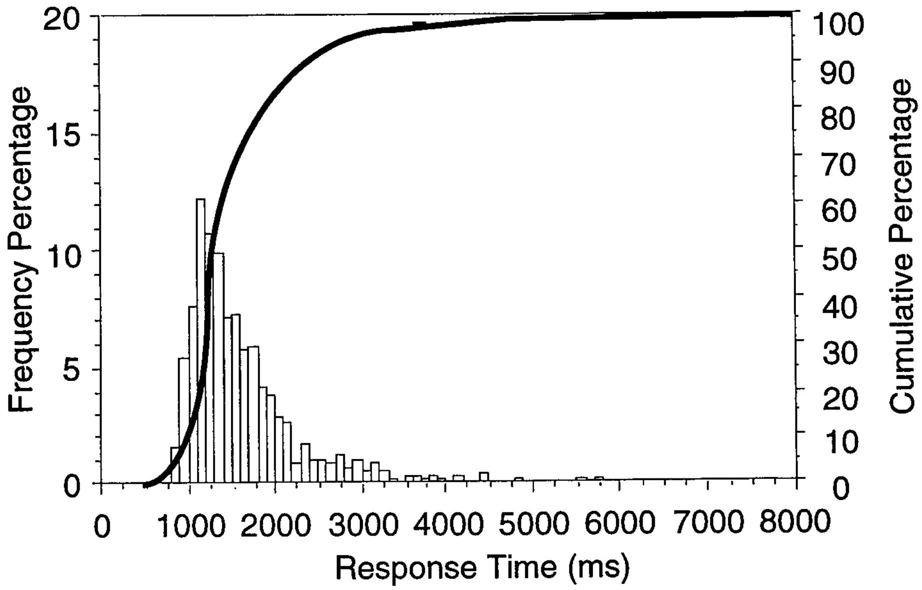


Figure 8. Task 1 response-time distributions.

A learning effect was evident for the task (Figure 9), with decreases in response times being small after approximately 6 trials. If the first 6 trials were removed from the dataset, the overall response time would decrease by 43 ms.

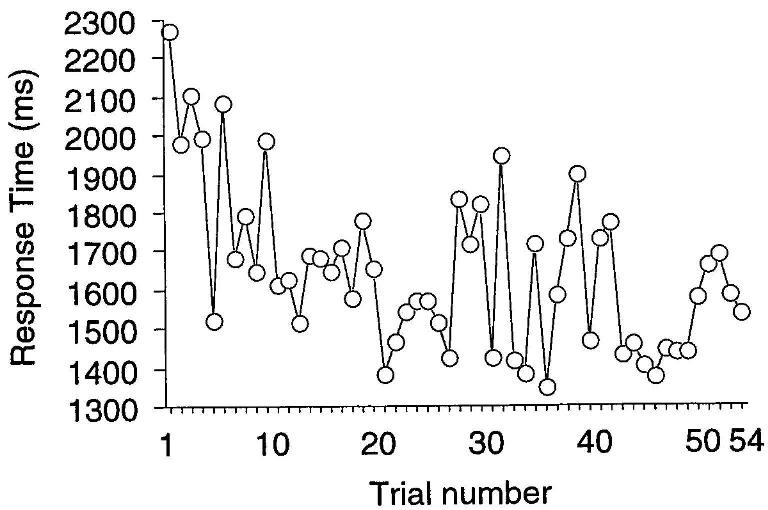


Figure 9. Learning curve for response times.

Factors in the ANOVA model for response time are shown in Table 6. 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 ANOVA for Task 1 is located in Appendix G.

Table 6. ANOVA factors for Task 1.

Classification	Factors	P-value
	Between subject	
Subject	Age	<.001
	Gender	.17
	Age * Gender	.33
	Subject (Age, Gender)	--
	Within subject	
Map Design	#Streets	<.001
	#Streets * Age	.004
	Point size	<.001
	Point size * Age	<.001
	%Labeled	.034
	#Streets * Point size	.003
	#Streets * Point size * Age	<.001
	#Streets * %Labeled	.78
	Point size * %Labeled	.002
Context Effect	Response gender	.73

Subject Effects

Age was the only significant subject effect, with older subjects taking 60 percent longer to respond than young subjects (means of 2027 and 1265 ms, respectively). (See Figure 10.) However, men generally took longer to respond than women.

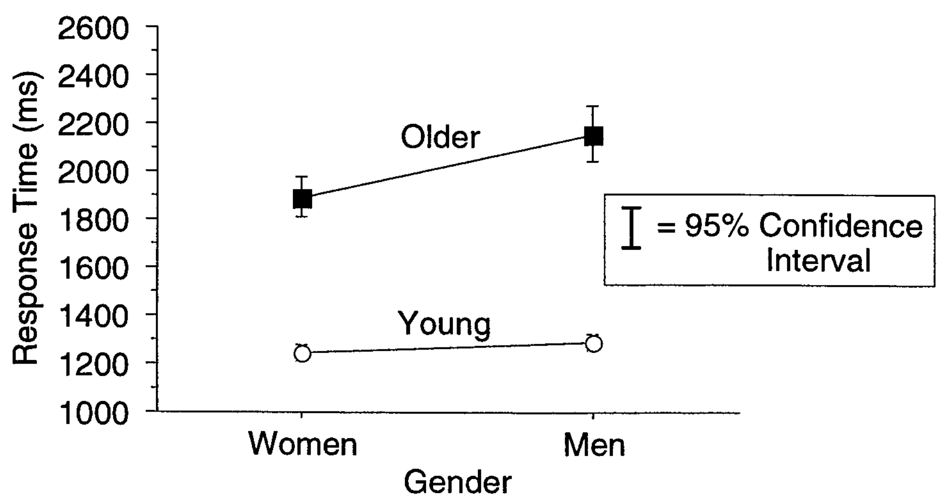


Figure 10. Effects of age and gender on response time for Task 1.

Map Design and Context Effects

The point size of street names, the number of streets shown on the map, and the percentage of streets labeled were all significant factors; however, the street name gender was not. Also, some of the factors interacted with age, namely point size and number of streets. Moreover, all interactions between point size, number of streets, and age were significant.

As point size increased from 10 to 14, response times decreased for older subjects yet were relatively unchanged for young subjects (Figure 11). Among older subjects, 14 point (mean = 1738 ms) yielded responses that were 10 percent (166 ms) better than 12 point and 40 percent (702 ms) better than 10 point.

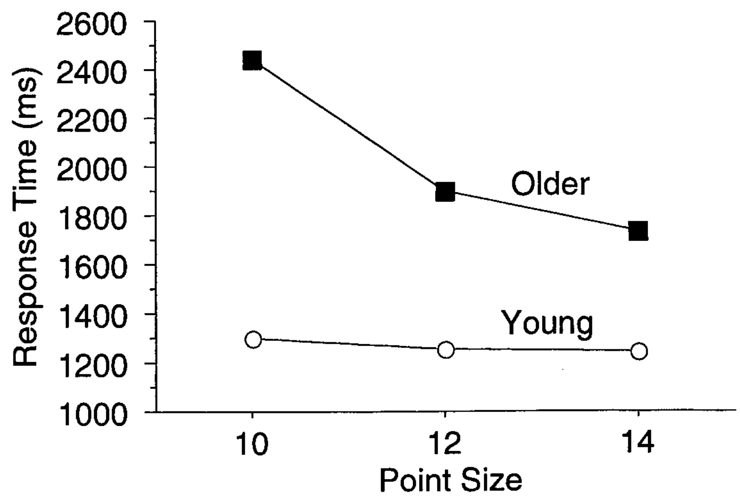


Figure 11. Interaction of point size and age for response time.

The interaction between the number of streets and age is shown in Figure 12. As the number of streets increased from 12 to 36, response times increased for older subjects (333 ms overall) and remained relatively constant for young subjects (56 ms overall).

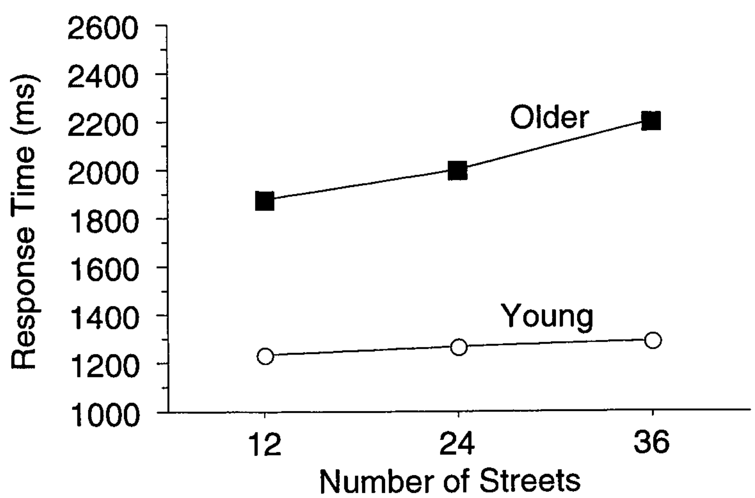


Figure 12. Interaction of number of streets and age for response time.

As the percentage of streets labeled increased from 33 to 100, response times increased for 12 and 14 point (Figure 13). However, for 14 point, the response time increase between 66 and 100 percent labeled was minimal (27 ms). This trend was also observed across the age effect. (Hence, the interaction of point size, percent labeled, and age was not significant.)

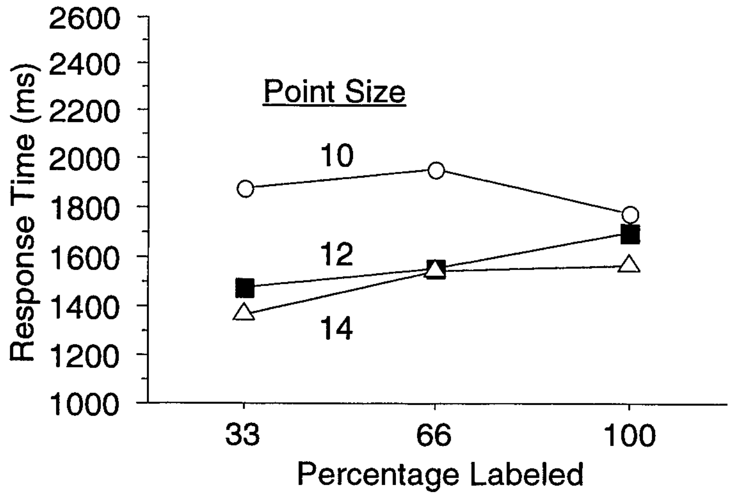


Figure 13. Interaction of percentage labeled and point size for response time.

Finally, no practical difference (12 ms, not statistically significant) was found between response times for male or female street names, as expected.

Response Time (Including larger point sizes)

In addition to the analysis above, the data for the higher levels of point size was also examined. To avoid serious confounding, only maps with 33 percent of streets labeled were examined, as that was the only condition used for the higher point sizes.

Factors in the ANOVA model for response time are shown in Table 7. The ANOVA for Task 1 is located in Appendix H. Remember that only maps with 33 percent of the streets were analyzed.

Table 7. ANOVA factors for Task 1 (additional point sizes).

Classification	Factors	P-value
	Between subject	
Subject	Age	.27
	Gender	.83
	Age * Gender	.92
	Subject (Age, Gender)	--
	Within subject	
Map Design	#Streets	.087
	#Streets * Age	.54
	Point size	<.001
	Point size * Age	<.001
	#Streets * Point size	<.001
	#Streets * Point size * Age	.003
Context Effect	Response gender	.71

The subject effects, age and gender, were not found to be significant. However, older subjects took an average of 48 percent longer to respond than young subjects (means of 1752 and 1185 ms, respectively).

Many map-design effects were found to be significant, the most notable being point size and the point-size-by-age interaction. As shown in Figure 14, young subjects were not affected by point size in the range of 12- to 20-point text (23 ms overall difference), and 10-point text yielded an only slightly higher (110 ms) response time. For older subjects, response time sharply decreased between 10 and 14 point, but point sizes of 14 to 20 were relatively the same.

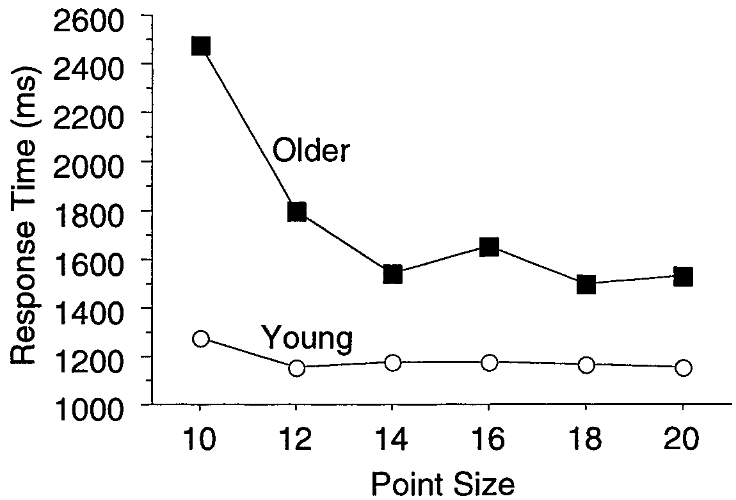


Figure 14. Interaction of point size and age for *33 percent labeled only.*

The significant interaction between the number of streets, point size, and age was also interesting. Older subjects with 10-point text was the only age/point size combination affected by the number of streets on the map. Within this specific group, response times increased by an average of 28 percent for each addition of 12 streets (means of 1894, 2441, and 3104 ms, respectively). For all other combinations within the interaction, the same trends remained true as were previously observed in Figure 14.

Task 1 Response-Time Prediction Model

The response-time prediction model for Task 1 (located below) includes 5 terms with 3 factors: age, number of streets, and point size. The linear effects of these factors are represented in the first 3 terms of the model. The last 2 terms in the model are various interactions between age, point size, and number of streets. The order of effect size, from largest to smallest, was age, point size, and number of streets.

$$\text{Response Time (ms)} = 2563 + 381*(A) + 8*(S) - 94*(P) + 88*(12 - P)*(A) + 4*(A + 1)*(S - 12)*\left(\frac{1}{11-P}\right)$$

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 ($10 \leq P \leq 14$)

The model shown above (and models in subsequent tasks) was generated by hand using a method for calculating the coefficients of each term. First, the overall mean was used as the starting integer term. Next, the code used for each term (discrete or continuous values) was established. For example, the age term used a ±1 discrete notation, while a variable such as the number of streets used a continuous scale. The mean values for each effect level were used to calculate the coefficients. Age, for example, had a total mean difference of 762 ms between young and older subjects; therefore, the coefficient was ±381 ms from the overall mean, depending on subject age. For variables with more than two levels, the middle level was assumed to be at the mean (an incorrect assumption); thus, an adjustment factor was included in the overall mean term. The interaction terms used inflection points as the basis for equation generation, where the inflection point became the value in the term (e.g., the 12 in "12 - P") so that the lines would be rotated about that point.

Predicted response times given by the model are plotted against all 1,080 actual response times in Figure 15. (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 35 percent.

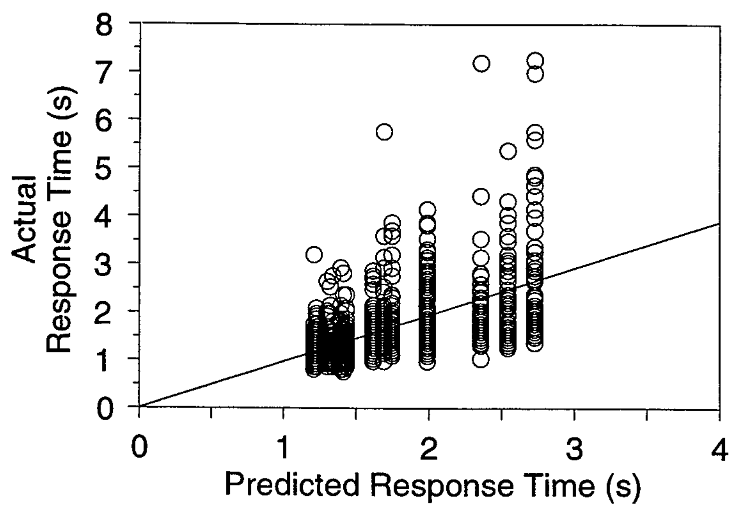


Figure 15. Predicted response time versus actual response time for Task 1.

Forward stepwise linear regression was also performed to verify the accuracy of the proposed model. All main effects in the proposed model likewise entered into the stepwise regression, which also retained identical coefficients. The R^2 value for this simplified model was 30 percent (5 percent less variance explained than the proposed model).

Task 2: What is the nth cross street?

The data analyzed by ANOVA for this task were all combinations of number of streets, percentage labeled, point size, and cross street named (1 and 3 only). Response was not balanced within this model, but the effects were considered to be negligible.

Error Rate

The overall error rate was 11.1 percent, or 120 out of 1,080 (20 subjects x 54 analyzable trials per subject) trials. The majority of errors occurred as a result of a mistake in counting cross streets. Twenty percent of all errors made were within the first 4 of the 54 analyzable trials, indicating a strong effect of learning on error rate (Figure 16). If the first 4 trials were removed from the dataset, the overall error rate would be 9.7 percent.

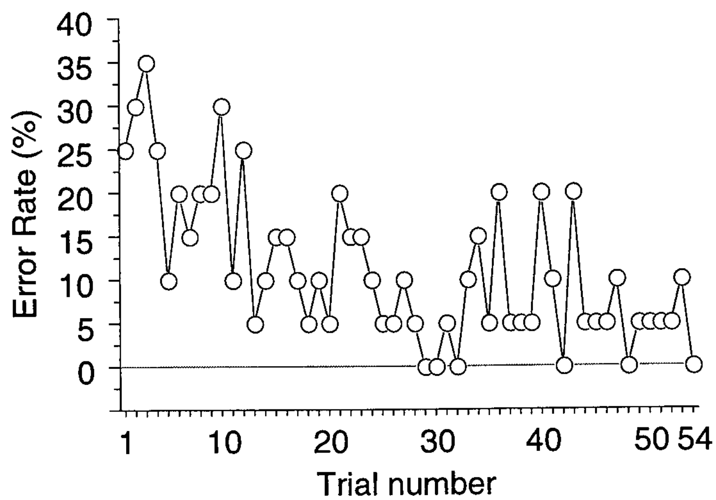


Figure 16. Learning effect on error rate.

A summary error-rate ANOVA model is shown in Table 8. The full error-rate ANOVA table for Task 2 is located in Appendix I.

Table 8. Summary error ANOVA model for Task 2.

Classification	Factors	P-value
	Between subject	
Subject	Age	<.001
	Gender	.053
	Age * Gender	.58
	Subject (Age, Gender)	--
	Within subject	
Map Design	#Streets	.007
	Point size	.54
	%Labeled	.23
	#Streets * Point size	.016
	#Streets * Point size * Age	.019
	#Streets * %Labeled	.007
	Point size * %Labeled	.064
Context Effect	Cross-street	.31
	%Labeled * Cross-street	.011

Subject Effects

Age was the only subject factor that significantly affected error rate. The mean error rate for older subjects (Figure 17) was 4 times that of young subjects (17.8 versus 4.4 percent). Gender was very close to significant, with the error rate for men being greater than that for women (13.1 versus 9.1 percent).

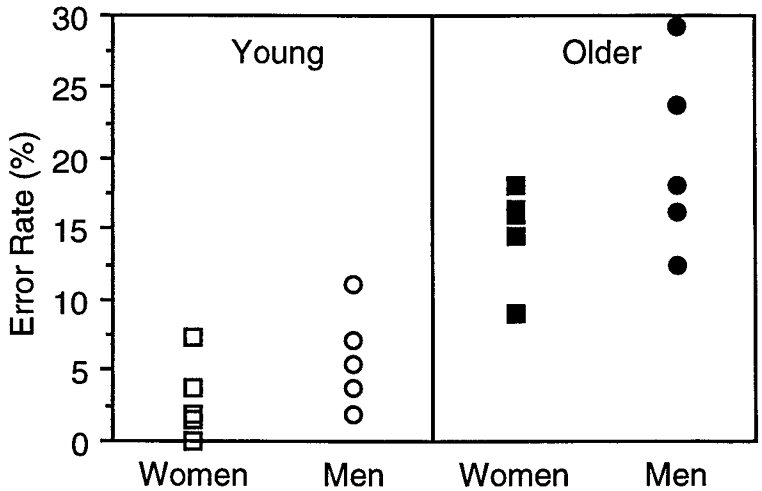


Figure 17. Task 2 error rates for all subjects, by age and gender.

Map Design and Context Effects

Error rate was significantly affected by the number of streets as well as the interaction between number of streets, point size, and age. For young subjects, 10 point at 36 streets was the only combination that was significantly different (Figure 18). For older subjects, as the number of streets increased from 12 to 36, the 14-point error rate greatly increased. This can be attributed to a clutter effect, where large point sizes can mask intersections and streets, thus increasing the likelihood of an error. Similarly, for maps with the same number of street names, additional unlabeled streets always increased error rate. However, for 10 point in both age groups, error rate decreased between 12 and 24 streets. With additional labeled streets on the map and a point size with no clutter effect, a particular cross street may have become more obvious.

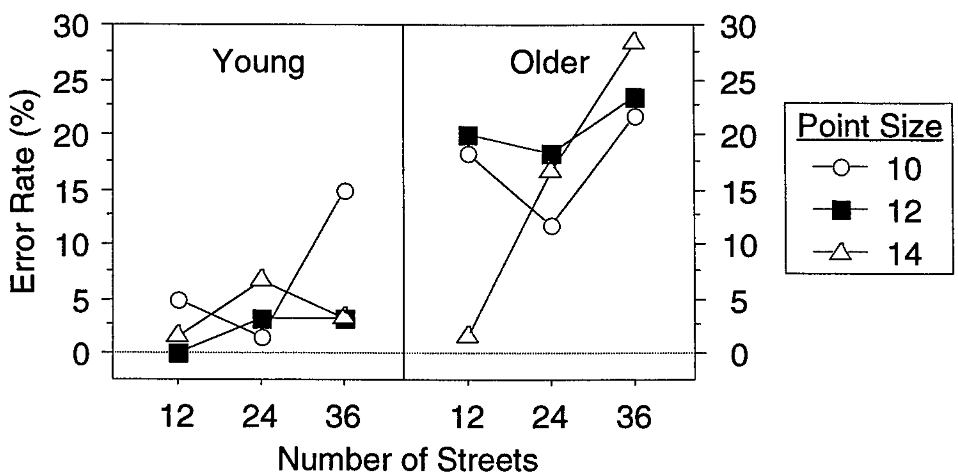


Figure 18. Interaction of number of streets, point size, and age for error rate.

The cross street named did not significantly affect error rate; however, the interaction between cross street named and percentage labeled was significant. For the first cross street named, error rate increased only slightly as percentage labeled increased (1.7 percent, or 3 errors, between levels). (See Figure 19.) However, for the third cross street named, error rate decreased as percentage labeled increased (5 percent, or 9 errors, between levels).

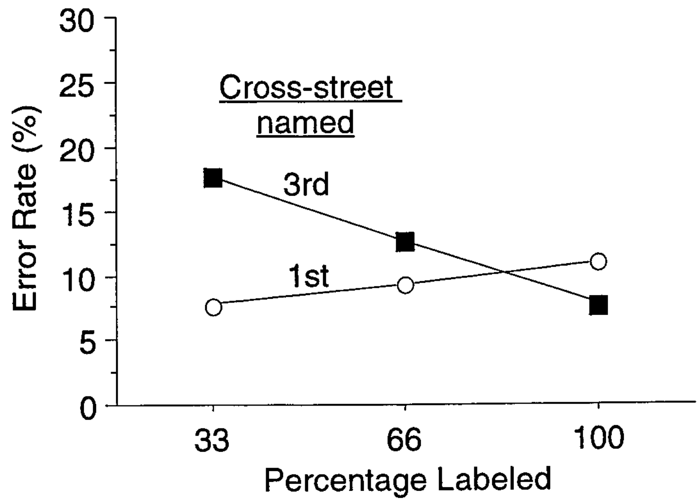


Figure 19. Interaction of cross street and percentage labeled for error rate.

Response Time

The mean response time for all data from Task 2 was 3332 ms with a range of 508 to 18368 ms (Figure 20). Response times under approximately 8000 ms accounted for 95 percent of the data.

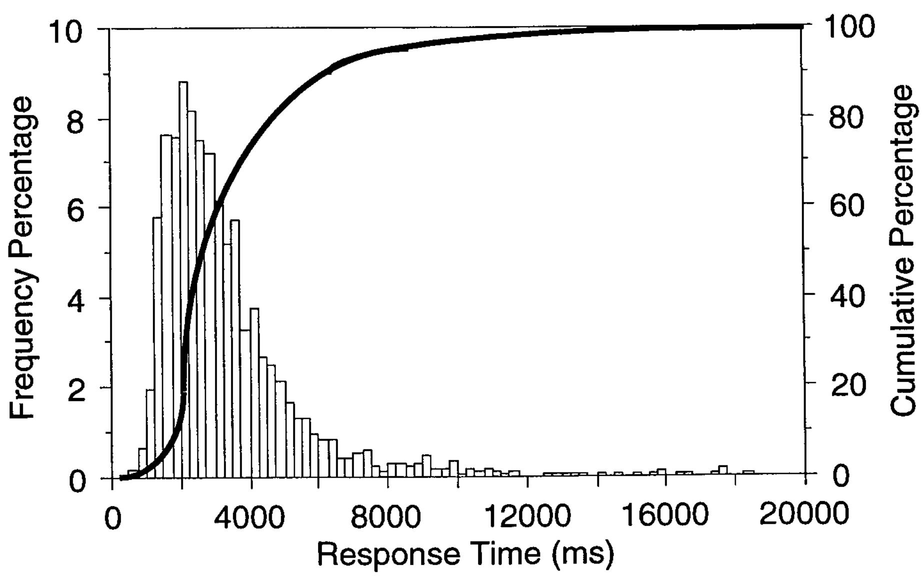


Figure 20. Task 2 response-time distributions.

A summary response-time ANOVA model is shown in Table 9. The full response-time ANOVA table for Task 2 is located in Appendix J.

Table 9. Summary response-time ANOVA model for Task 2.

Classification	Factors	P-value
	Between subject	
Subject	Age	<.001
	Gender	.93
	Age * Gender	.38
	Subject (Age, Gender)	--
	Within subject	
Map Design	#Streets	<.001
	Point size	.86
	%Labeled	.12
	%Labeled * Age	.032
	#Streets * Point size * Age	.027
	#Streets * Point size * %Labeled	<.001
Context Effect	Cross-street	<.001
	#Streets * Cross-street	.002
	Point size * Cross-street	.39
	%Labeled * Cross-street	<.001

Subject Effects

Age was the only subject effect that significantly affected response time, with older subjects taking 44 percent longer to respond than young subjects (3114 versus 2158 ms). (See Figure 21.)

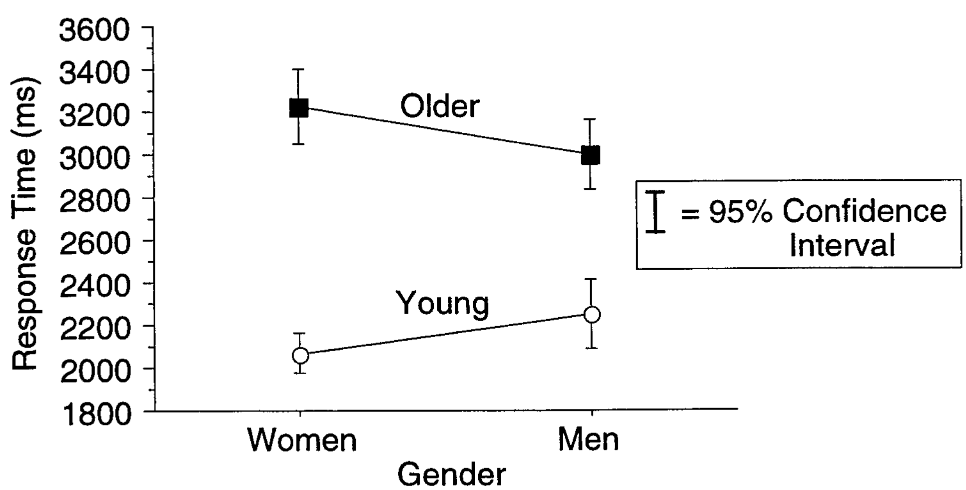


Figure 21. Effects of age and gender on response time.

Map Design and Context Effects

The number of streets on the map was the only main effect of map design that affected response times, increasing 354 ms between 12 and 36 streets. The interaction between percentage of streets labeled and age was also significant. For young subjects, no discernible pattern was observed over percentage labeled (overall difference of 181 ms). (See Figure 22.) However, for older subjects, as percentage labeled increased from 33 to 100, response times decreased by 274 ms.

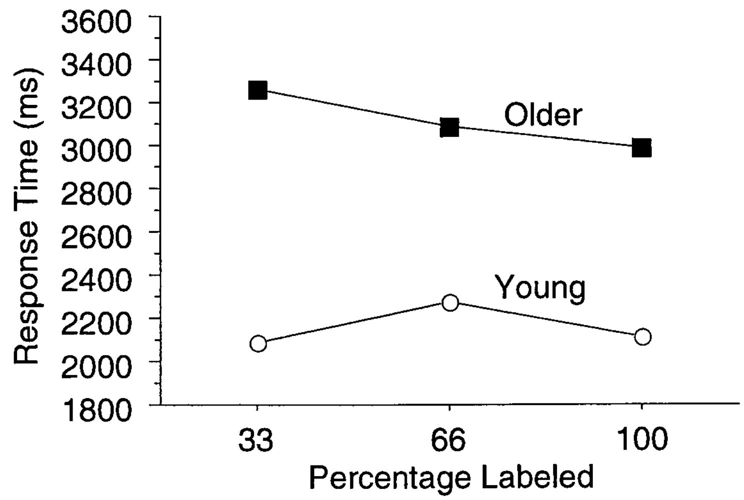


Figure 22. Interaction of percentage labeled and age.

Point size did not significantly affect the response times in this counting task. Through all interactions, no consistent trends were observed regarding an optimal point size.

The cross street named significantly influenced response times, with the third cross street yielding 55 percent longer response times than the first cross street (3208 versus 2064 ms). Also, the interaction between the cross street named and the number of streets on the map was significant. For the first cross street named, as the number of streets increased from 12 to 36, response times remained relatively unchanged (difference of 175 ms). (See Figure 23.) However, for the third cross street named, a large increase in response time was observed between 12 and 24 streets (541 ms), and 24 and 36 streets were effectively the same (8 ms difference).

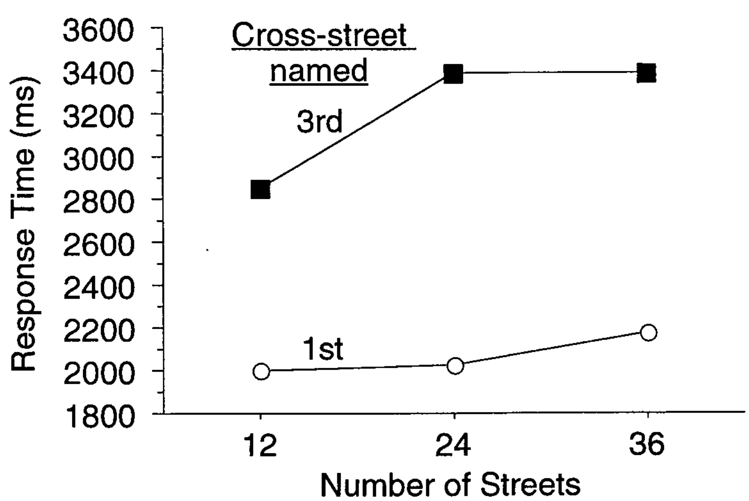


Figure 23. Interaction of cross street named and number of streets for response time.

Task 2 Response-Time Prediction Model

The Task 2 response-time prediction model (located below) includes 4 terms with 3 factors: age, number of streets, and target cross street. The linear effects of these factors are represented in the first 3 terms of the model. The last term is the interaction between number of streets and target cross street. The order of effect size, from largest to smallest, was target cross street, age, and number of streets. The absolute value in this term was included to model a change in slope that occurred at the fourth cross street named. It must be noted that this model was fitted using all data points (4 extra levels of target cross street).

Response Time (ms) = 82 + 582*(A) + 61*(S) + 523*(X) + 19*(Abs|X - 4|)*(24 - S)

where:

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

S = Number of streets ($S \geq 1$)
X = Target cross street ($X \geq 1$)

Predicted response times given by the model are plotted against all 1,980 actual response times in Figure 24. (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 38 percent.

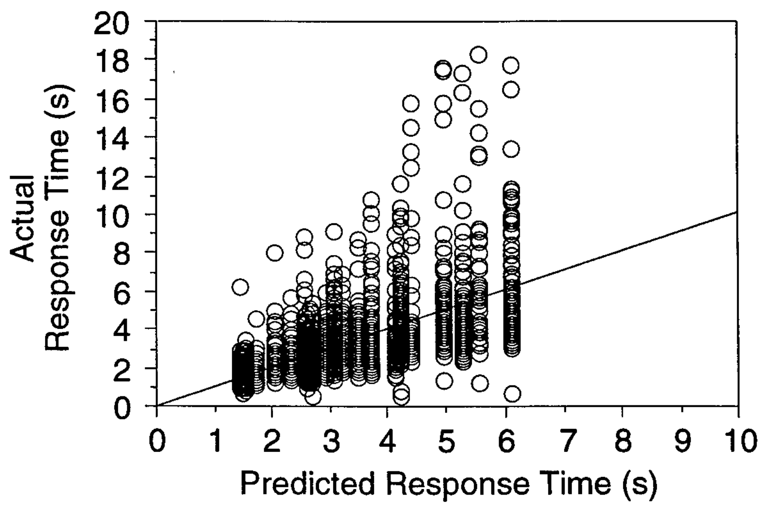


Figure 24. Predicted response time versus actual response time for Task 2.

To verify the proposed model, forward stepwise linear regression was also performed. Each model included the effects of age, number of streets, and cross street named, while excluding the effects of point size and percentage of streets labeled. However, the coefficients of the included factors differed within each model. These coefficients differed because the proposed model was intentionally designed to accurately predict low response times, while knowingly overestimating high response times. The model was designed in that way because the low response-time range is where most practical work will be performed. Stepwise regression generates coefficients that will minimize overall variance, regardless of the practical implications.

Task 3: Where is the target street?

Error Rate

The overall error rate was 11.5 percent, or 249 out of 2,160 (20 subjects x 108 trials per subject) trials. Table 10 summarizes the errors for each response. Errors in this task were grouped into 3 distinct categories: misses, location errors, or slips. Misses occurred when the subject failed to find a name that was actually on the map (72 percent of total errors). Location errors occurred when the subject found the street on the map, but did not correctly identify the location of the street. Slips were when the subject intended to respond correctly but inadvertently pressed the wrong key. Location errors and slips accounted for the remaining 28 percent of the errors.

Table 10. Number of errors by response. The correct response is in bold.

	Response					
Stimuli	ahead	behind	left	right	not there	Total
ahead	**460**	8	3	7	62	540
behind	6	**469**	11	11	43	540
left	3	7	**219**	0	51	280
right	1	4	7	**225**	23	280
not there	1	0	0	1	**538**	540
Total	471	488	240	244	717	2160

A summary error-rate ANOVA model is shown in Table 11. The full error-rate ANOVA table for Task 3 is located in Appendix K.

Table 11. Summary error ANOVA model for Task 3.

Classification	Factors	P-value
	Between subject	
Subject	Age	.01
	Gender	.84
	Age * Gender	.74
	Subject (Age, Gender)	--
	Within subject	
Map Design	#Streets	<.001
	#Streets * Age	.006
	Point size	.094
	%Labeled	<.001
	#Streets * Point size	.19
	#Streets * %Labeled	.016
	Point size * %Labeled	.81
Context Effect	Location	<.001
	#Streets * Location	<.001
	Point size * Location	.17
	%Labeled * Location	.25

Subject Effects

Age was the only subject factor that significantly affected error rate. The mean error rate for older subjects was double that of young subjects (15.6 versus 7.5 percent) but varied greatly between subjects (Figure 25).

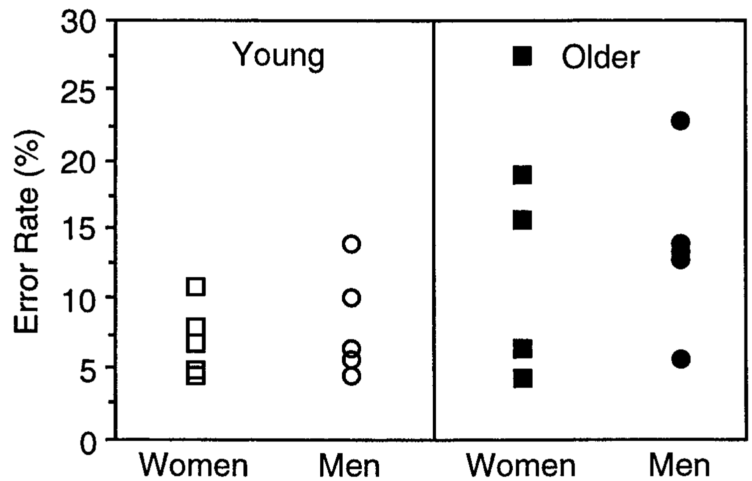


Figure 25. Task 3 error rates for all subjects, by age and gender.

Map Design and Context Effects

Factors of map design that significantly affected error rate were the number of streets on the map and the percentage of streets labeled. The combination of these factors generated the number of street names on the map (e.g., 12 streets with 33 percent labeled = 4 street names), which greatly affected error rate. Increasing the number of street names increased the error rate (Figure 26), except at high numbers of names, where error rate leveled off. Furthermore, the increase in error rate observed between 4 and 12 names was small compared with the increase observed between 12 and 24 names.

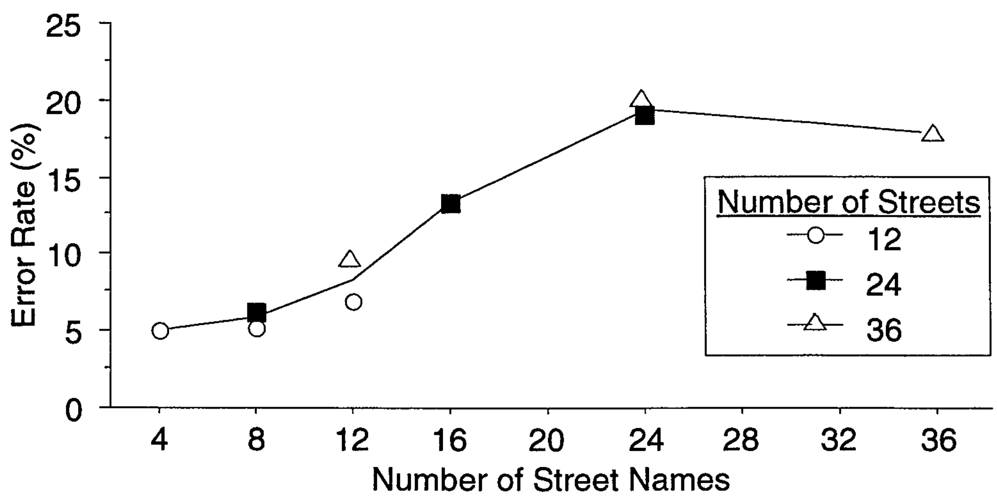


Figure 26. Error rates for the number of street names on the map.

The location of the target street was an experimental context effect that significantly influenced error rate. Four street locations were possible: ahead, behind, to the side (left/right), or not there. When the name was not on the map ("not there"), the error rate was practically 0 percent. Also, locations of ahead and behind were found to be very similar in error rate (average error rate = 14 percent), while locations to the side had a higher error rate (17.8 percent).

Response Time

The mean response time for Task 3 was 5377 ms with a range of 825 to 21148 ms (Figure 27). The mean time for this task was much higher because of the need to search through as many as 36 names before responding.

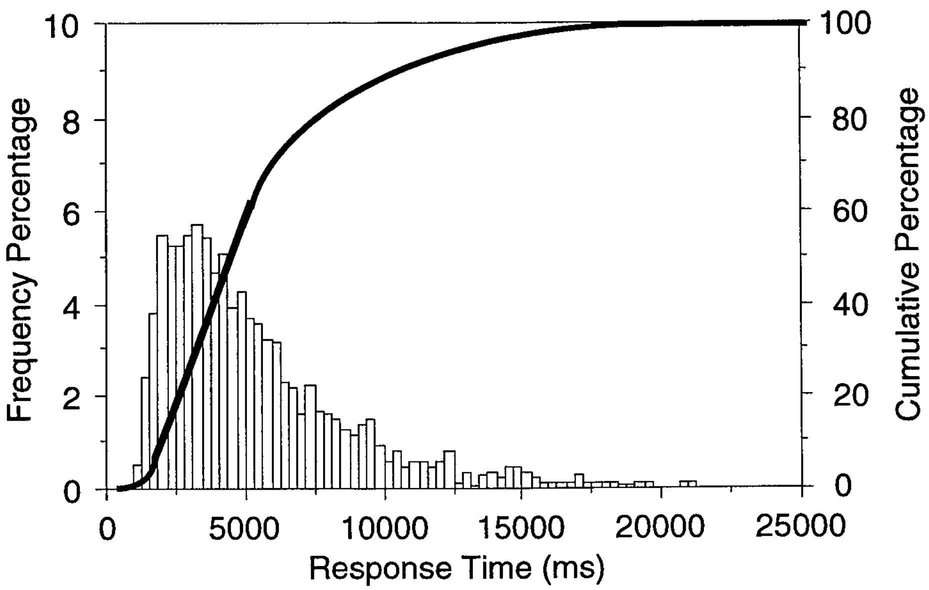


Figure 27. Task 3 response-time and cumulative distribution.

Factors included in the response-time ANOVA model are shown in Table 12. The ANOVA for Task 3 is located in Appendix L.

Subject Effects

Age was the only subject effect found to be significant, with older subjects taking 66 percent longer to respond than young subjects (6712 versus 4042 ms), a percentage increase similar to that of Task 1 (Figure 28). Gender and the age-by-gender interaction were not statistically significant. However, older men took 27 percent longer to respond than older women (7500 versus 5924 ms).

Table 12. Summary response-time ANOVA model for Task 3.

Classification	Factors	P-value
	Between subject	
Subject	Age	<.001
	Gender	.15
	Age * Gender	.069
	Subject (Age, Gender)	--
	Within subject	
Map Design	#Streets	<.001
	#Streets * Age	.004
	Point size	<.001
	%Labeled	<.001
	%Labeled * Age	.002
	#Streets * Point size	.15
	#Streets * %Labeled	<.001
	Point size * %Labeled	.039
Context Effect	Location	<.001
	#Streets * Location	<.001
	Point size * Location	.001
	%Labeled * Location	<.001

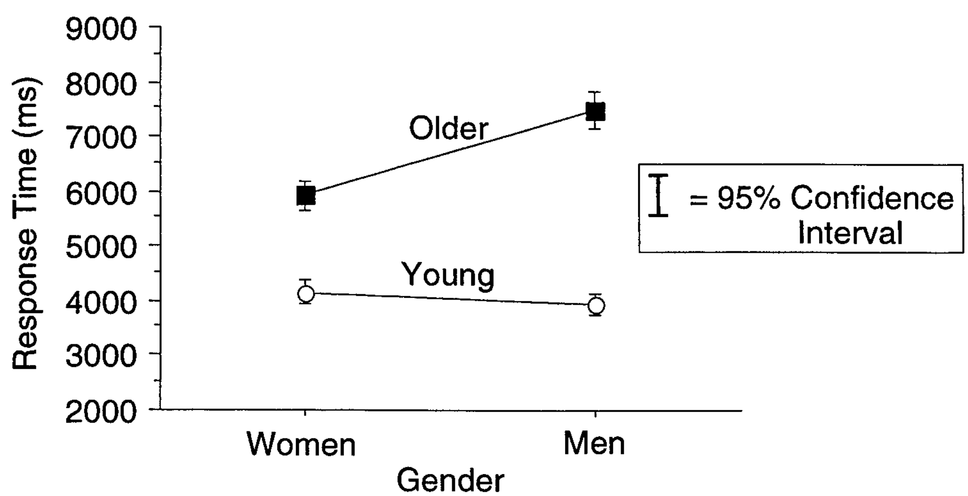


Figure 28. Task 3 age-by-gender interaction for response time.

Map Design and Context Effects

The number of streets on the map, the percentage of streets labeled on the map, and the point size of the street names were all significant factors. Also, all interactions between these 3 factors were significant except for number-of-streets-by-point-size.

As the number of streets and percentage of streets labeled increased, response times also increased (Figure 29). When replotted as a function of the number of street names (Figure 30), response times increased by 200 ms for each additional name. The response times for maps with 36 street names did not follow the linear trend because subjects were most likely to give up on the trial.

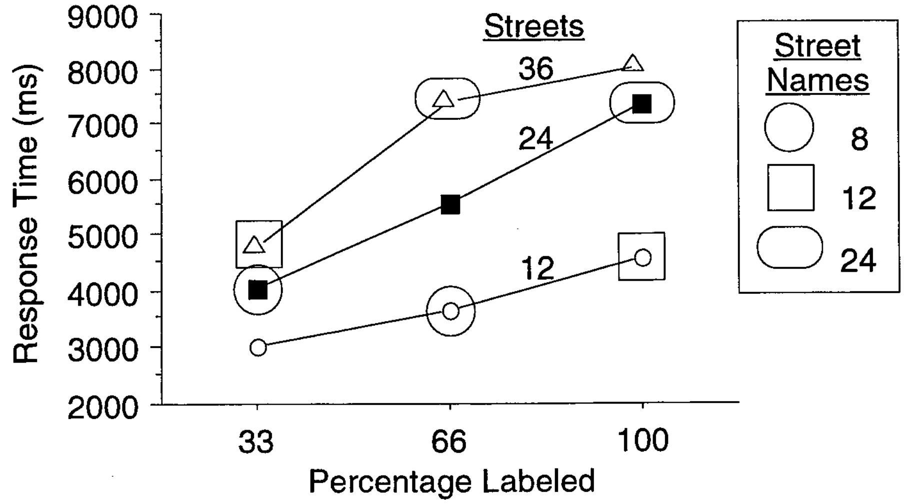


Figure 29. Response-time as a function of the percentage of streets labeled and the number of streets.

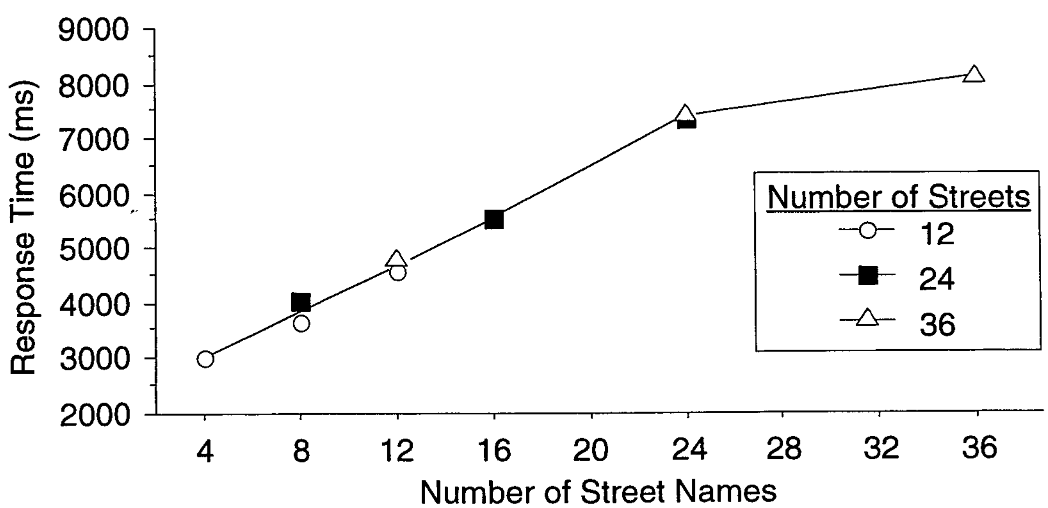


Figure 30. Response times for the number of street names on the map.

As point size increased from 10 to 14, response times decreased by 330 ms for each 2 points in size. This effect was smaller than the effects of the number of streets and the percentage of streets labeled. The interaction of point size and percentage labeled was also significant, where response times decreased as point size increased within 66 and 100 percent labeled (Figure 31) but remained nearly constant when only 33 percent of the streets were labeled.

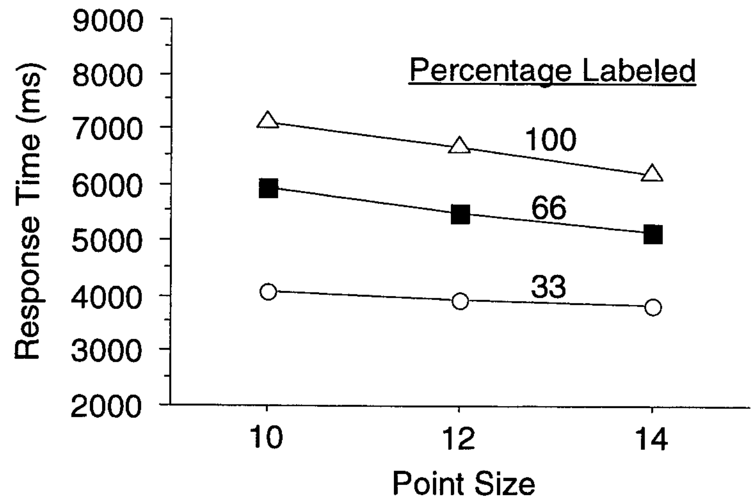


Figure 31. Effects of point size and percentage labeled on response time.

Response times in street-searching were also dependent on the target street location. In general, response times increased between responses of "ahead," "behind," "to the side," and "not there" across all numbers of street names (Figure 32). One exception was at 4 street names, where "not there" had the fastest response times. Also note the drastic increase in "not there" response times for 24 and 36 street names.

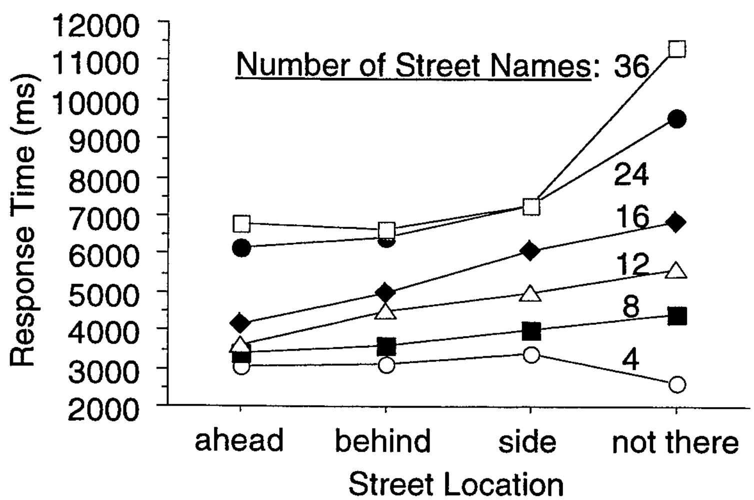


Figure 32. Effects of street location and number of street names on response time.

Task 3 Response-Time Prediction Model

The response-time prediction model for Task 3 (next page) includes 7 terms with 6 factors: age, number of streets, point size, percentage of streets labeled, target location, and search result. The linear effects of these factors (not including search result) are represented in the first 5 terms of the model. The next term in the model is the interaction between number of streets and percentage of streets labeled. 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 age, number of streets, percentage labeled, target location, and point size.

$$\text{Response Time (ms)} = [\,2305 + 1137*(A) + 75*(S) - 81*(P) + 24*(PL) + 551*(L) + (S - 22)*(PL - 55)\,] * SR$$

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 ($10 \leq P \leq 14$)
PL = Percentage of streets labeled ($1 \leq PL \leq 100$)

$$L = \text{Target location} \begin{cases} -1 \text{ for ahead} \\ 0 \text{ for behind} \\ +1 \text{ for side} \end{cases}$$

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

Predicted response times given by the model are plotted against all 2,160 actual response times in Figure 33. (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 52 percent.

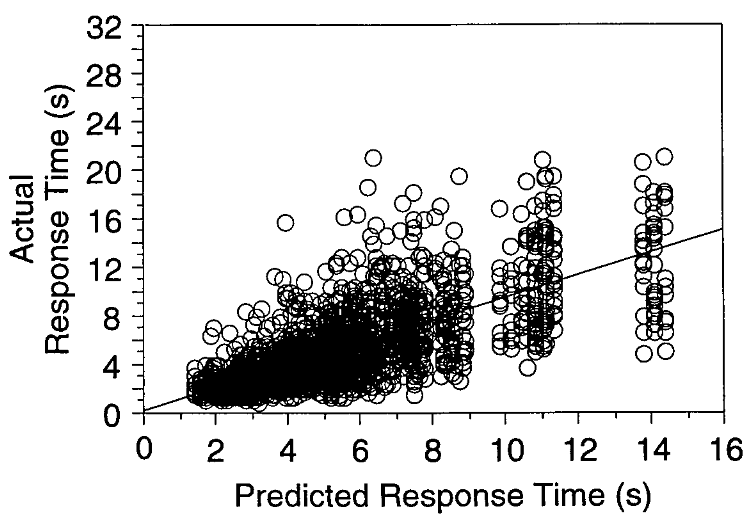


Figure 33. Predicted response time vs. actual response time for Task 3.

Forward stepwise linear regression was also performed to verify the accuracy of the proposed model. The main effects included by each model were the same; however the coefficients differed slightly (mean difference of 5 percent). As in the regression for Task 2, the reason for this discrepancy is that the proposed model was intentionally designed to predict low response times best, as this is the area where most practical work will be performed. Stepwise regression generates coefficients to minimize variance. Therefore, since the variability generally increases as response times increase, stepwise regression attempts to predict high response times more accurately, regardless of the practical implications.

Task 4: Different display locations

Error Rate

Out of 1,080 total trials (20 subjects x 54 test trials per subject), 8 errors occurred (0.7 percent). The errors appeared to be randomly distributed over age, gender, and image position. The error rate was low because subjects had performed the same task earlier in the experiment and the task was relatively simple.

Response Time

The overall Task 4 mean response time was 1671 ms with a range of 571 to 6474 ms. Response times under approximately 3000 ms accounted for 95 percent of the data. The distribution and statistics were very similar to those of Task 1, as expected.

A learning effect was apparent when the low image position was shown first. (See Figure 34.) Response times decreased substantially over the first 5 trials of the task before leveling out. If the first 5 trials were removed from the dataset, the overall response time would decrease by 77 ms. As shown in Table 13, no learning effect was evident within the other conditions when compared with the low position in block sequence 2.

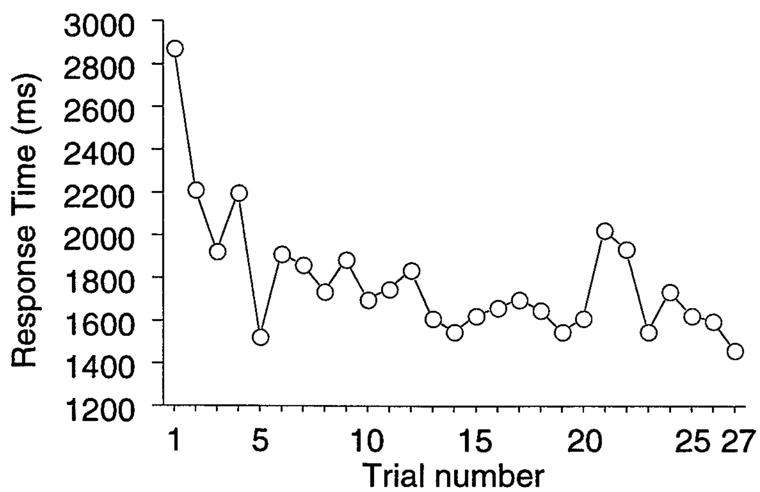


Figure 34. Learning effect for the low position when shown first (block sequence 2).

Table 13. Mean response times and largest difference *over first 5 trials only.*

Block Sequence (1=high shown before low, 2=low shown before high)	Image Position	Mean Response Time (ms) (first 5 trials)	Largest time difference (ms) (first 5 trials)
1	High	1872	506
	Low	1802	878
2	High	1525	451
	Low	2128	1284

Factors included in the response-time ANOVA model are shown in Table 14. An abridged ANOVA table for Task 4 (not including higher order interactions) appears in Appendix M.

Table 14. Response-time ANOVA factors for Task 4.

Classification	Factors	P-value
	Between subject	
Subject	Age	<.001
	Gender	.33
	Age * Gender	.61
	Block Sequence	.67
	Subject (Age, Gender)	--
	Within subject	
Map Design	Image Position	.001
	Image Position * Block Sequence	.009
	#Streets	.002
	Point size	<.001
	Point size * Age	.001
	#Streets * Point size	.58
	%Labeled	.002
	%Labeled * Age	.032
	#Streets * %Labeled	.22
	Point size * %Labeled	.015

Subject Effects

Age was the only significant subject effect, with older subjects taking 47 percent longer to respond than young subjects (means of 1992 and 1351 ms, respectively). Gender, block sequence, and the age-by-gender interaction were not significant. Block sequence was the order in which the subject observed image positions (high before low or low before high).

Map Design Effects

Image position was found to be a significant effect, where response times for the low position were 10 percent longer than the high position (means of 1751 and 1592 ms, respectively). Moreover, the interaction between image position and block sequence was significant. Figure 35 shows the effects of image position and order on response time. A learning effect was apparent when the low position was shown first, with a response-time decrease of 282 ms to the high position. The previously mentioned effect of image position was also evident, with a distinct separation between the high and low positions when shown either first or second.

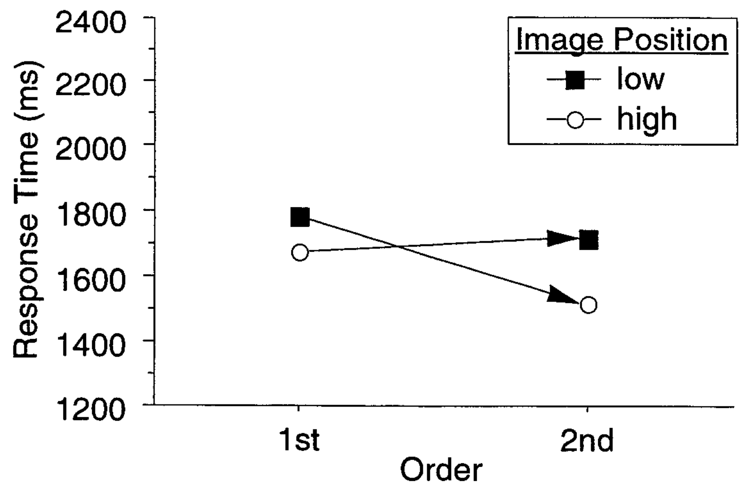


Figure 35. Effects of image position and order on response time.

The effect of point size was significant, with 10 point averaging 250 ms greater than 12 and 14 point. However, a more accurate description of the point-size effect was the interaction of point size and age. The mean 10 point response time for older subjects was 23 percent (430 ms) higher than 12 and 14 point, and was only 5 percent (69 ms) higher for young subjects (Figure 36). The response-time difference was highly significant for older subjects and was not significant for young subjects.

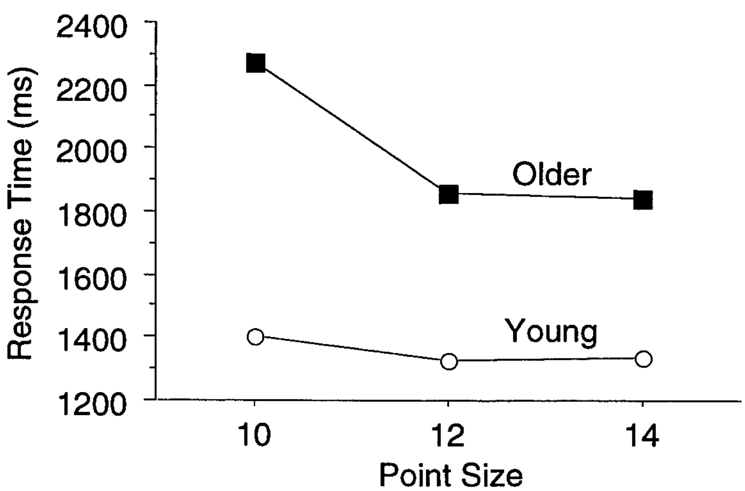


Figure 36. Interaction of point size and age for response time.

The number of streets on the map and the percentage of streets labeled were both significant effects. The combination of these effects, the number of street names on the map, was useful in describing the clutter effect observed within 14 point for older subjects. As the number of street names on the map increased, the response times for older subjects tended to increase for 14 point (Figure 37). Moreover, the other point sizes, 10 and 12, did not display this trend over either age group.

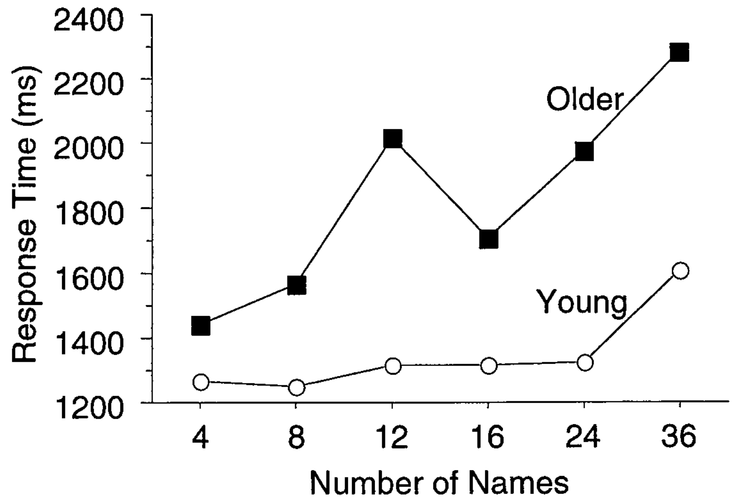


Figure 37. Effects of number of names and age for *14 point only.*

Comparison of Task 4 with Task 1

The mean response time of identical trials between Tasks 1 and 4 were compared to determine whether the tasks were equivalent. Only trials and conditions common to both tasks were compared (e.g., high position only). The mean response times of Tasks 1 and 4 were 1592 and 1629 ms respectively. Each task displayed similar range and distribution statistics.

Factors included in the task-comparison ANOVA model for response time are shown in Table 15. The context effect "Task" refers to the statistical comparison of the tasks. An abridged ANOVA table for task comparison (not including higher order interactions) is located in Appendix N.

Table 15. Response-time ANOVA factors for comparison of Task 1 and Task 4.

Classification	Factors	P-value
Subject	Task	.50
	Task * Age	.17
	Task * Gender	.94
	Task * Age * Gender	.46
	Task * Subject (Age, Gender)	--
Map Design	Task * #Streets	.30
	Task * Point size	.20
	Task * Point size * Age	.027
	Task * %Labeled	.56

The difference in mean response time between tasks (37 ms) was not significant (subject effect "Task"), indicating that the tasks were equivalent. Task also did not affect the map-design factors, with the exception of the interaction between point size and age ("Task * Point size * Age").

Results of the point-size-by-age interaction showed both similar and differing trends between tasks. Two results were common to both tasks: young subjects displayed no significant differences between point sizes, and 12 and 14 point were generally equivalent within each age group (Figure 38). The 10 point mean response time differed between tasks for older subjects; the Task 4 response time (2144 ms) was 244 ms (about 11 percent) less than in Task 1.

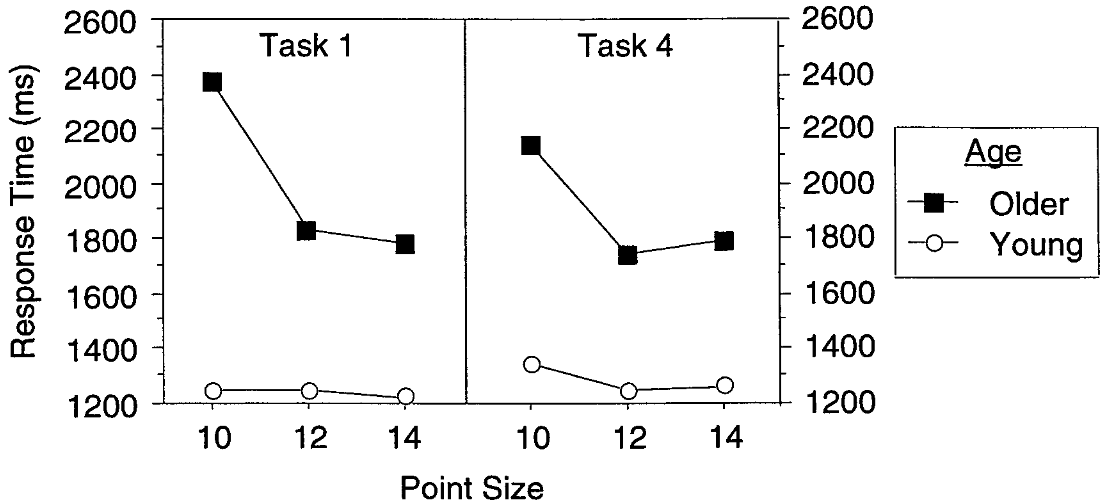


Figure 38. Interaction of point size and age for response time, split by task. (Note: Task 1 results are only from trials comparable to Task 4.)

CONCLUSIONS

How long does it take to read an electronic map?

The time required to read a map was directly dependent on the task performed. This experiment examined 3 tasks of varying difficulty. Task 1 (What street are you on?) had a relatively low difficulty level, requiring only one glance to the map. Response times ranged from 1 to 3 seconds, with a mean of about 1.6 seconds. Task 2 (What is the nth cross street?) was considerably more difficult, and the response times were dependent on the target cross street number. Some trials were low in difficulty and required only a single glance to the map, but many others were more difficult and required multiple glances. The range of response times was 1.4 to 7.5 seconds, with a mean of 3.3 seconds. Task 3 (Where is the target street?) was also very difficult, and response times increased as the number of names to search increased. Generally, most trials required more than a single glance to the map. Response times ranged from 1.8 to 12.5 seconds, with a mean of 5.4 seconds.

How did subject age and gender affect map reading time?

For all tasks performed in this experiment, age was a profoundly significant subject factor, while gender was never found to be significant. The effect of age was relatively uniform across tasks, with older subjects taking 44 to 66 percent longer to respond than younger subjects. Also, the factors examined in this experiment affected older subjects to a greater degree than younger subjects.

How many streets should be labeled; how many should be displayed?

For every task, increasing the number of streets on the map increased response times, though the effect was considerably larger for the number of labeled streets, depending on the task. In a simple task such as Task 1 (On-street task), response times increased approximately 8 ms per street (labeled or unlabeled). However, when performing the more difficult search task (Task 3), each additional labeled street added about 200 ms, while each additional unlabeled street added only about 14 ms. Also, the error rate sharply increased when more than 12 streets were labeled, yet marginally increased when additional unlabeled streets were added. Therefore, the number of labeled streets on the map should be held to 12 or fewer to allow for accurate map reading.

However, in Task 2 additional unlabeled streets increased the error rate by increasing map clutter. Therefore, displaying 24 or fewer streets is recommended to ensure accurate map reading for a wide variety of tasks where roads are represented by one line thickness and no color coding. That number might increase for situations where additional coding is provided. However, the recommended number of streets should not change very much for different display sizes (here, a 5-inch diagonal display was tested) because the viewers task is dependent upon the number of items on the map. As was suggested by this research, the visual angle between display elements (which determines display size) was important only to the extent that clutter was a factor.

What size text should be used?

Throughout the experiment, text point sizes of 10, 12, and 14 were examined. Young subjects did not display a clear preference within this range of text sizes, showing little or no performance differences in any of the tasks. On the other hand, older subjects were very sensitive to point size, with 10 point generally leading to longer response times and more complaints. The most prevalent differences between text point sizes appeared in Task 1 (On-street task) because it was predominantly a reading task, where older subjects performed much better when reading 14-point text. Furthermore, text that was 10 point or smaller was beyond the readable range for many older subjects and should not be used in navigation systems. Therefore, 14-point text is the preferred size for street labels on displays viewed at 30 inches (76 cm), though a smaller size (no less than 12 point) should be considered with high map clutter and larger sizes should be considered with very low map clutter.

As the text size, the number of streets, and the number of street names increase, map clutter also increases. Clutter can significantly increase error rates and response times, especially when performing counting or search tasks, because cross streets and intersections can be masked by the text. Two effective ways to decrease clutter are to decrease the point size or to increase the display size. However, even on a larger display, additional streets will still increase response times. Therefore, if the number of street names exceeds 16, then the effects of clutter can be reduced by either reducing the text label size to 12 point or increasing the display size (with a 5-inch diagonal display as a baseline). Depending on the particular viewing distance being used, an appropriate point size can be calculated using the visual angles shown in Table 2 of the Test Plan.

Which display location should be used?

The final task performed in this experiment (Task 4) examined 2 distinct display locations, a high position on the center console (as used in all other tasks) and a low position located 8 inches (20.3 cm) below, tilted upward. The task performed was the same as Task 1. Response times for the high position were an average of 10 percent faster than the low position, even for that simple task. Generally, glancing to the high position could be performed without moving the head, but looking to the low position usually required a small downward head movement. Therefore, it is recommended that in-vehicle navigation systems be located high on the center console.

How can response time be predicted?

Table 16 summarizes the response-time prediction equations for the three tasks of this experiment. Driver response times for each task can be predicted using these equations for particular map-design characteristics.

Table 16. Summary of response-time prediction equations.

Response Time (ms)		Prediction Equation
Task 1 (On-Street)	=	$2563 + 381*(A) + 8*(S) - 94*(P) + 88*(12 - P)*(A) + 4*(A + 1)*(S - 12)*\left(\frac{1}{11-P}\right)$
Task 2 (Cross Street)	=	$82 + 582*(A) + 61*(S) + 523*(X) + 19*(Abs\lvert X - 4\rvert)*(24 - S)$
Task 3 (Where is?)	=	$[\, 2305 + 1137*(A) + 75*(S) - 81*(P) + 24*(PL) + 551*(L) + (S - 22)*(PL - 55)\,] * SR$

where:

$A = \text{Age} \begin{cases} -1 \text{ for Young subjects} \\ +1 \text{ for Older subjects} \end{cases}$	S = Number of Streets ($S \geq 1$)
$L = \text{Target Location} \begin{cases} -1 \text{ for ahead} \\ 0 \text{ for behind, or not there} \\ +1 \text{ for side} \end{cases}$	P = Label Point Size ($10 \leq P \leq 14$)
PL = Percent of Streets Labeled ($1 \leq PL \leq 100$)	X = Target Cross Street ($X \geq 1$)
$SR = \text{Search Result} \begin{cases} 1.0 \text{ if found} \\ \left(\frac{\#names}{3 + 0.5 * (\#names)}\right) \text{ if not found} \end{cases}$	

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APPENDIX A - Participant Consent Form

Subject: ____________ Date: ____________

MAP LEGIBILITY STUDY
PARTICIPANT CONSENT FORM

The purpose of this experiment is to determine how to maximize the readability of electronic maps that might appear in cars of the future. You will be driving a simulated car in the laboratory. While driving, a map will appear and you will locate particular streets and identify their names. Times and errors will be recorded. 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 he 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 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 B - 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? Y / N
T	R	R	L	T	B	L	R	L	B	R	B	T	R	
20/200	20/100	20/70	20/50	20/40	20/35	20/30	20/25	20/22	20/20	20/18	20/17	20/15	20/13	______ which?

APPENDIX C - Instructions to Subjects

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 2 hours to complete and you will be paid $40 for your time. You will be asked to operate a driving simulator while performing 4 different map reading tasks. For the first task, I will show slides of maps and ask you to identify the street on which you are driving. For the second task, you will locate the name of a particular cross street. For the third task, you will find particular streets. Before starting, there are some forms you need to fill out. Afterwards, I will give you more detailed instructions.

Bio and Consent Forms

First, please read and sign this consent form, and then turn the page and fill out the biographical form.

I want to emphasize 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 will 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 will 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 study examines how features such as street name letter size, the number of names on the map, and the number of streets on the map affect the ease of reading an electronic map.

For your first practice session, you will be shown slides with one name on each slide. The name will either be a male or female. The name could be oriented vertically or horizontally. After the slide appears, determine whether the name is male or female and 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.

While responding to the maps, you will be driving the simulator. Please drive 30 mi/hr during the sessions. Keep your eyes on the road when a map is not being shown. A brief tone will alert you when a new map appears. Respond to the map as rapidly and accurately as possible, but remember your primary task is to drive safely. If you make a mistake, a long, low frequency tone will be presented. Do not correct your response as only the first keypress is accepted.

I will give you additional instructions for the first map task after the simulator practice drive without the map task is completed. Do you have any questions?

As a reminder, some people 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 will stop the simulator. Do not try to be a hero. If you are ready, hold on to the wheel and I will start the simulator.

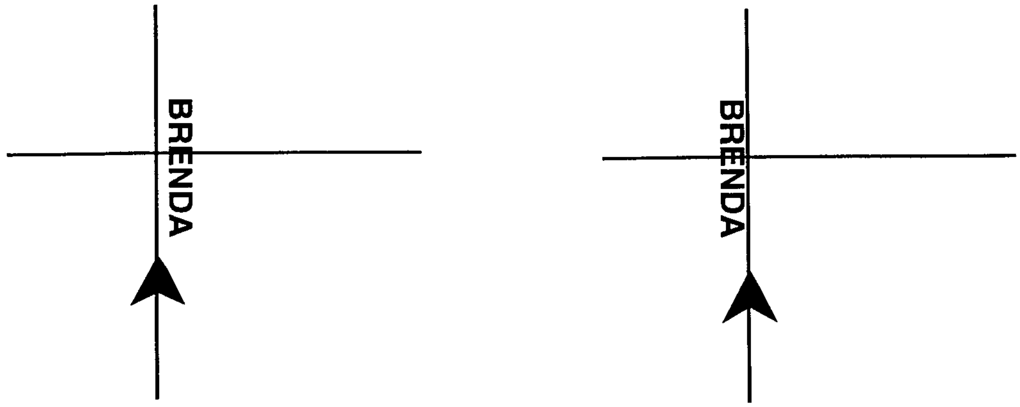
Start simulator. Let subject drive for one minute. Take a short break, ask how they're feeling. Let subject drive for another minute, then start the practice task. Just before the practice starts say:

Remember,

- **driving safely at 30 mi/hr is your priority,**
- **after hearing the tone, look at the map for the street that you are 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 On-Street task.

For the first task, you will be shown slides of maps with varying numbers of streets and street labels. Respond using the response board in the same manner as you did during the practice session, to the following question: Is the name of the street that you are traveling on male of female? Let me show you some examples. Show subject example of map.



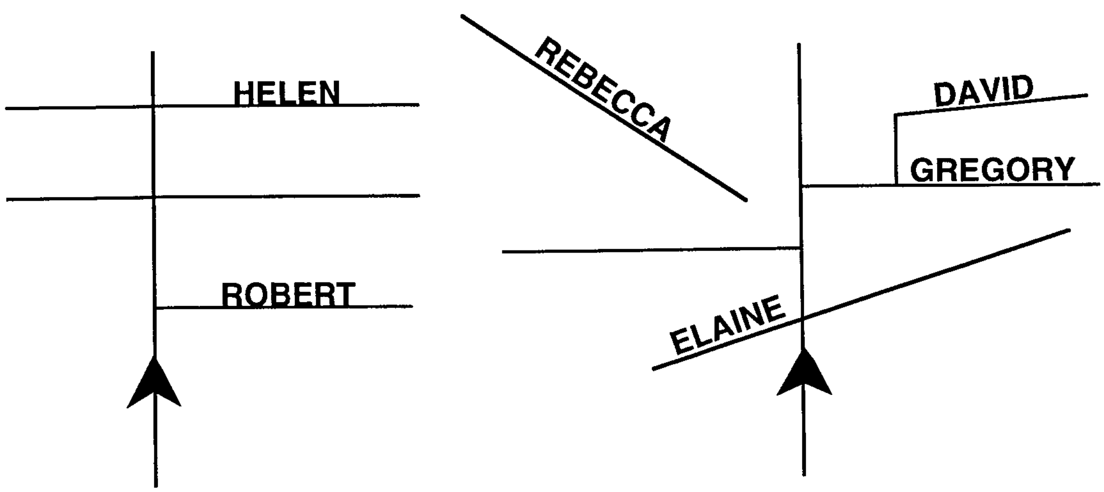
Here are the two different ways to show you are driving on Brenda street. Notice the triangle icon located on the street. This icon indicates your current position.

Please drive the simulator at 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.

If you like, you can take a short break before we 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 eighth) male or female? I will read the number of the cross street to find 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 of responses and example map.



In the figure on the left, both Helen and Robert are cross streets. Robert is the first cross street, while Helen is the third. 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 third. If you look at the response board, notice two more response keys have been added. For this task, the four possible responses are male, female, "not there", and "not labeled". For the fourth cross street in the figure to the left, the triangle being your current location, your response would be "not there". In this case, press the left-most key with your thumb. For the second cross street in the figure on the left, your response would be not labeled. This cross street is on the map, but it is not labeled. The male and female keys will be used the same as they were during the first task. If asked to identify the gender of the fourth cross street for the figure on the right, your response would be not there. Do you understand the definition of a cross street? Give further explanation if the subject does not understand. **Feel free to reorient the response board so it is comfortable to use.**

Great, let's start the second task.

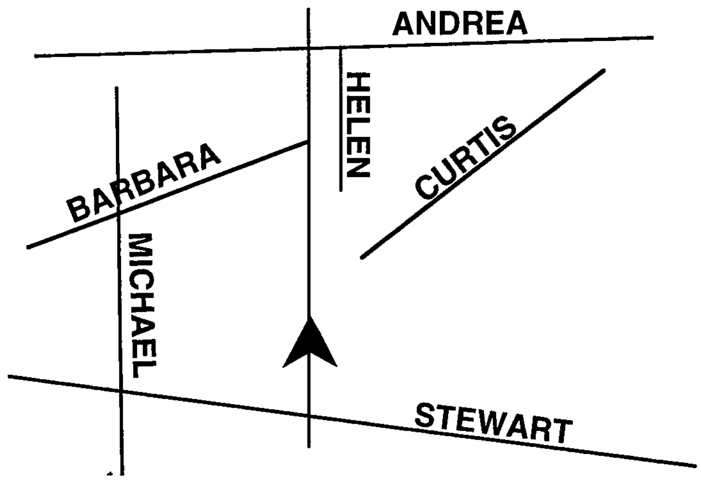
Run the second task.

Let's take 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 will 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 of responses.

Run the practice session for task 3.

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



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

Run task 3.

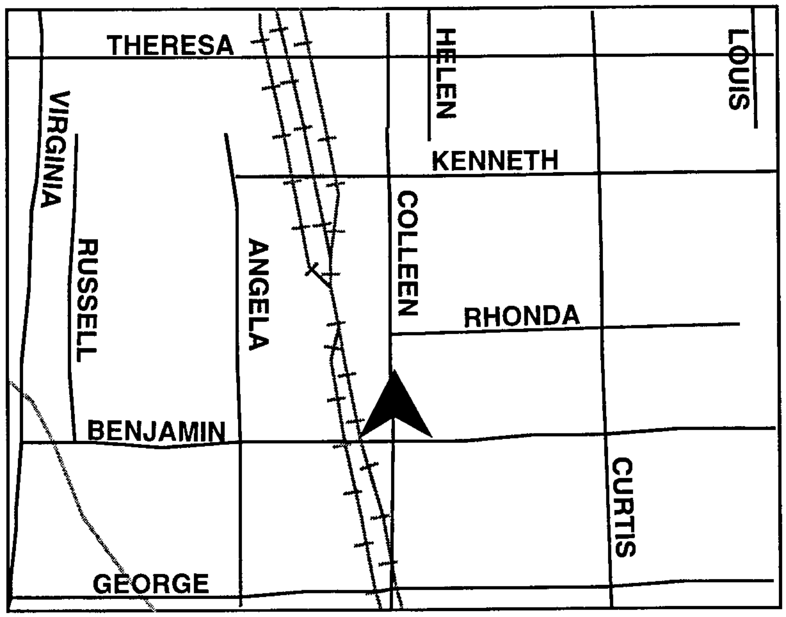
The fourth, and final, task is a repetition of the first task, to identify the street being driven, male or female. However, here the task is split into two groups of trials. In one group, the map will be high on the instrument panel. In the other it will be low.

As a reminder, if the street name is male, press the left key with your index finger. If the street name is female, press the right key with your middle finger. Do you have any questions? Give further instruction if subject is unclear about task. **OK, we will now start the final task.**

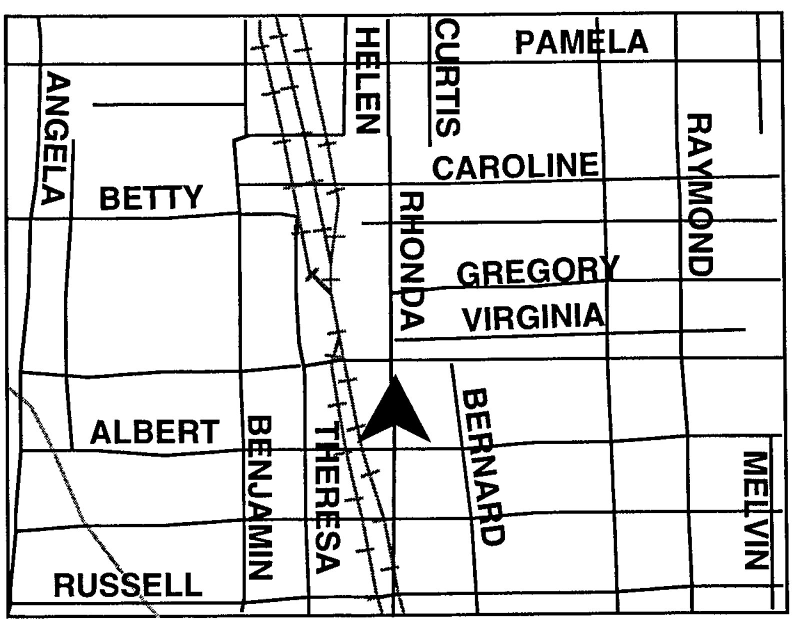
Run Task 4.

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

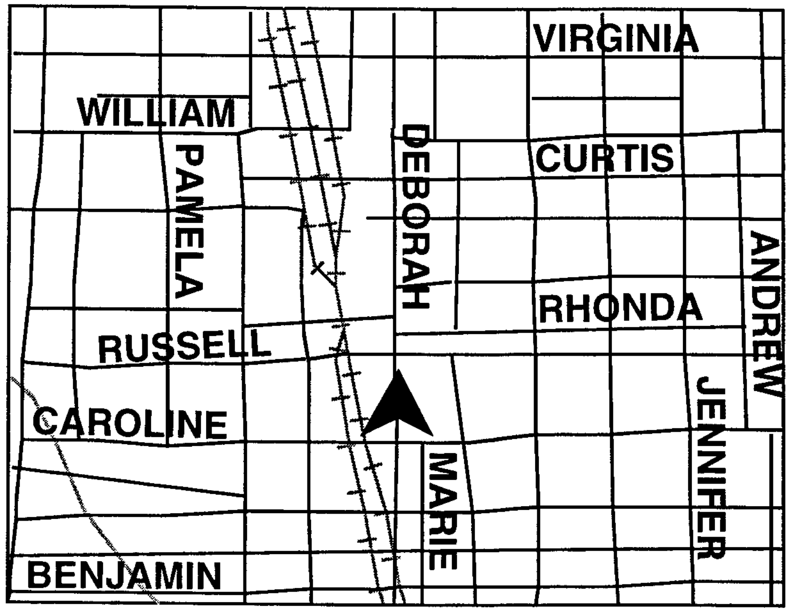
APPENDIX D - Sample Maps



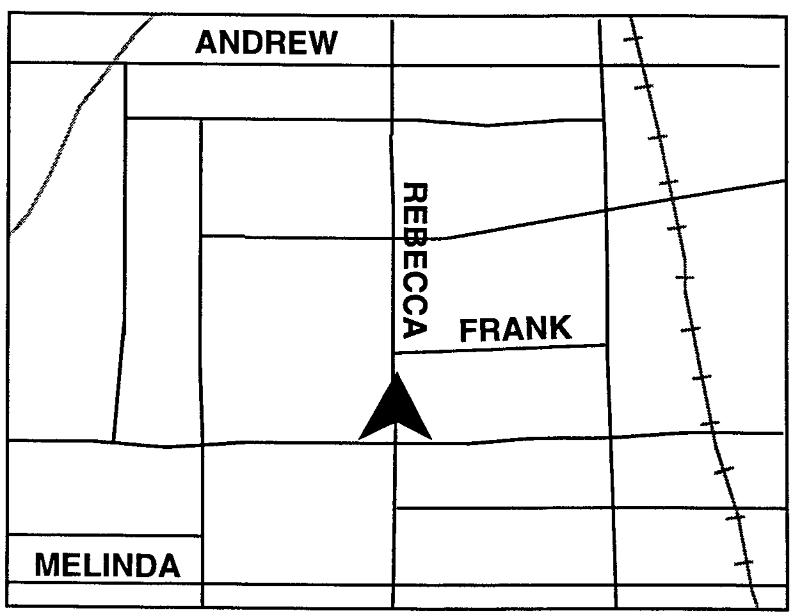
Map Template 1, 12 Streets, 100 Percent Labeled, 10 Point



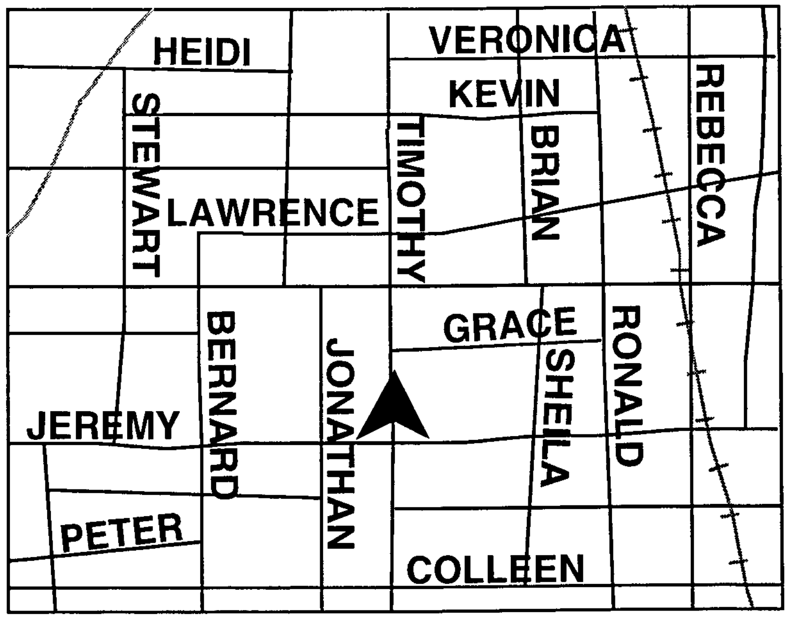
Map Template 1, 24 Streets, 66 Percent Labeled, 12 Point



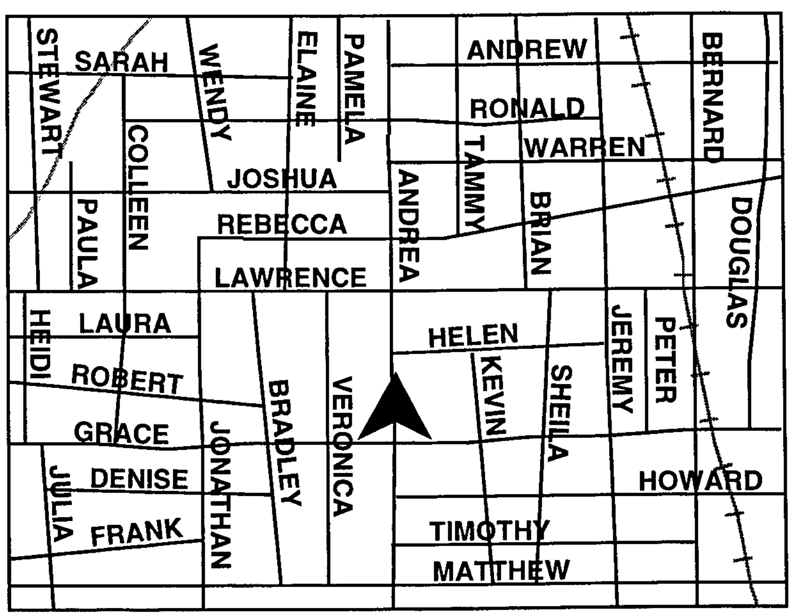
Map Template 1, 36 Streets, 33 Percent Labeled, 14 Point



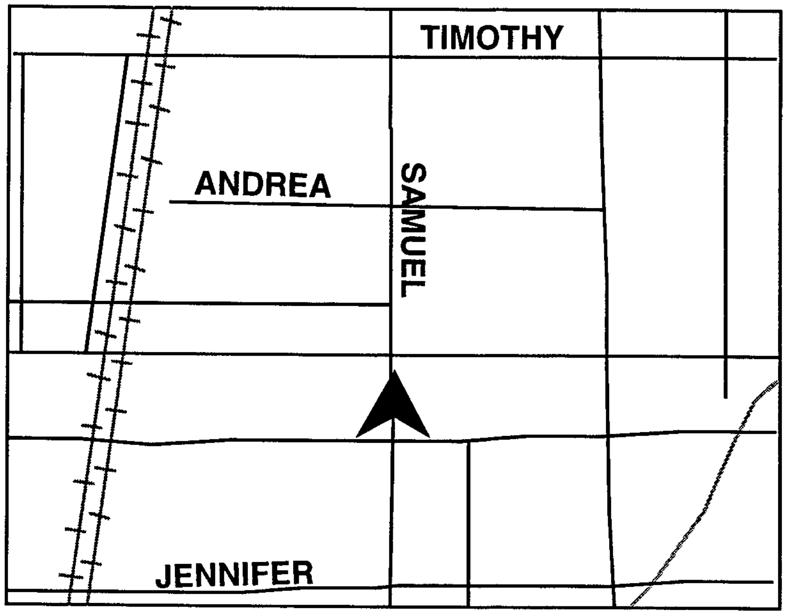
Map Template 2, 12 Streets, 33 Percent Labeled, 12 Point



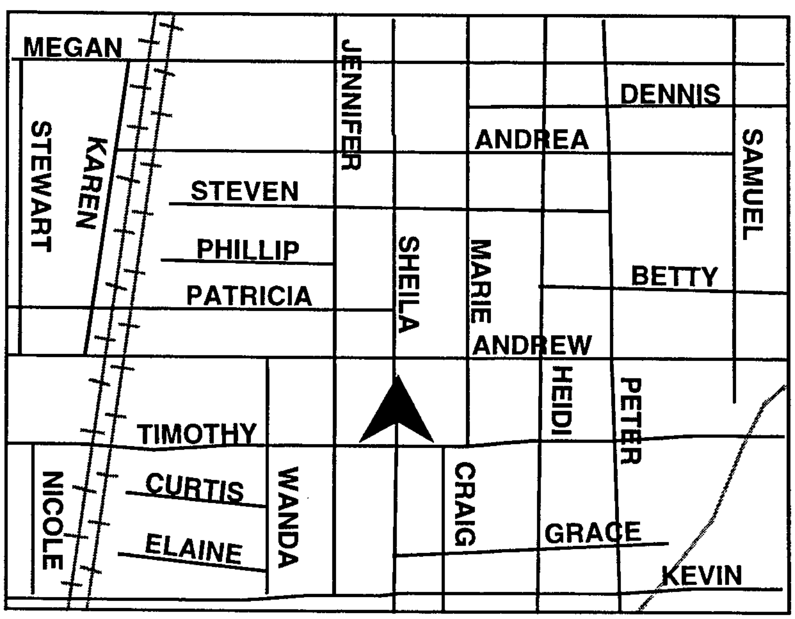
Map Template 2, 24 Streets, 66 Percent Labeled, 14 Point



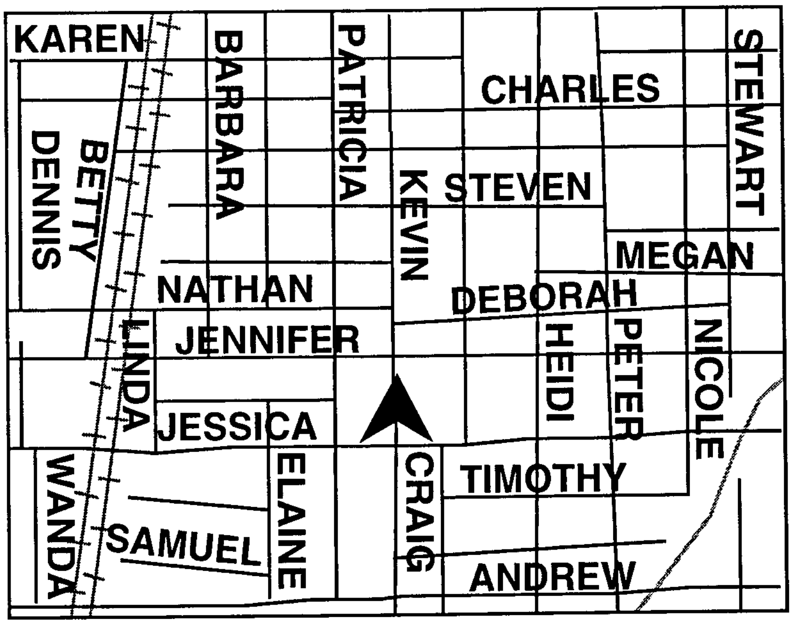
Map Template 2, 36 Streets, 100 Percent Labeled, 10 Point



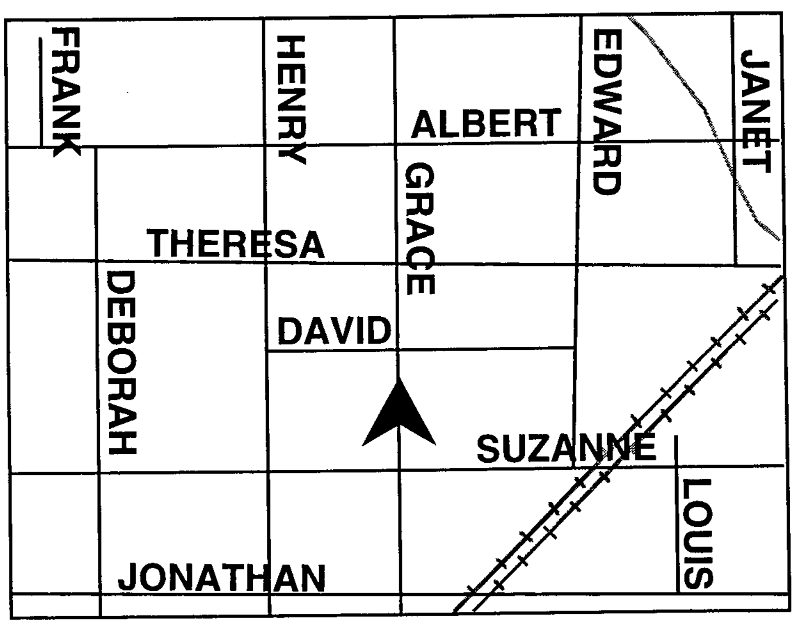
Map Template 3, 12 Streets, 33 Percent Labeled, 12 Point



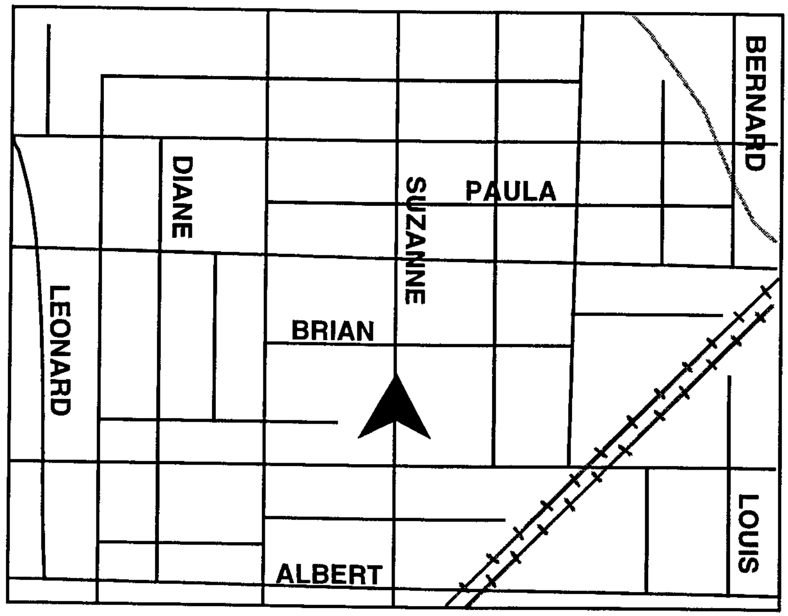
Map Template 3, 24 Streets, 100 Percent Labeled, 10 Point



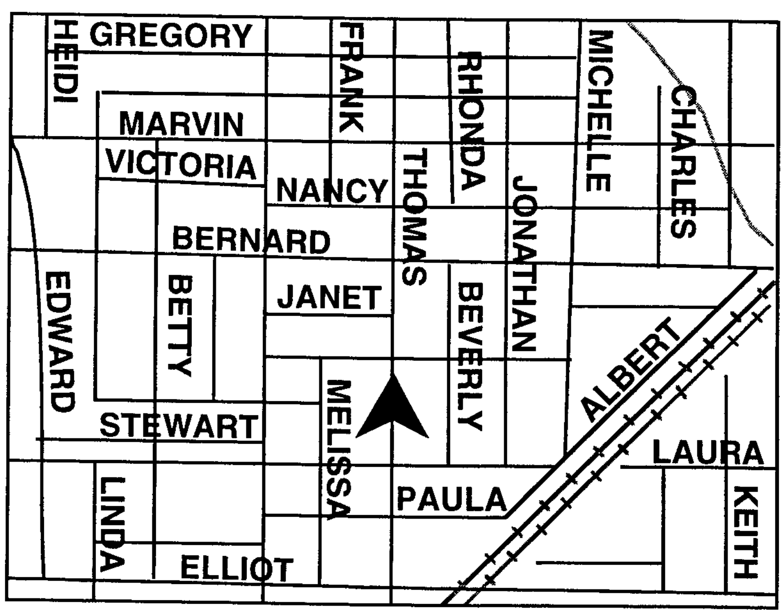
Map Template 3, 36 Streets, 66 Percent Labeled, 14 Point



Map Template 4, 12 Streets, 100 Percent Labeled, 14 Point



Map Template 4, 24 Streets, 33 Percent Labeled, 10 Point



Map Template 4, 36 Streets, 66 Percent Labeled, 12 Point

APPENDIX E - Experimental Conditions for Each Task

Practice Task 1 Experimental Conditions

Point Size	Orientation	Response	Name	Start
14	horizontal	female	Karen	Start 1
12	vertical	female	Deborah	
14	vertical	female	Michelle	
14	horizontal	male	Matthew	
10	horizontal	male	Jeffrey	
14	horizontal	male	Nathan	Start 2
14	vertical	male	Frank	
12	horizontal	male	Howard	
12	horizontal	female	Veronica	
14	vertical	female	Patricia	
12	horizontal	female	Dorothy	Start 3
10	horizontal	female	Andrea	
10	horizontal	female	Nicole	
14	horizontal	female	Monica	
10	vertical	female	Helen	Start 4
10	vertical	male	Henry	
14	vertical	male	Peter	
10	horizontal	male	Edward	
12	vertical	male	Kevin	
12	vertical	female	Heidi	Start 5
12	vertical	male	Curtis	
12	horizontal	male	Timothy	
10	vertical	female	Betty	
10	vertical	male	Stewart	

Task 1 Experimental Conditions

Streets	Point Size	Percent Labeled	Response	Map	Start
12	14	66	male	3	Start 1
36	12	100	female	2	
12	18	33	female	1	
24	14	33	male	4	
36	14	66	female	2	
36	14	33	male	4	
36	12	66	male	4	
24	12	66	female	3	
24	10	66	male	3	
36	18	33	female	3	
12	10	100	male	4	
36	10	66	male	1	
24	14	66	male	4	
24	14	100	male	2	
12	12	100	female	1	Start 2
36	14	100	female	3	
24	12	100	male	3	
24	14	100	female	4	
36	20	33	female	1	
12	20	33	female	2	
12	12	66	male	1	
36	12	33	female	2	
24	10	33	male	1	
12	14	100	male	3	
12	12	66	female	4	
12	12	33	female	2	
36	12	100	male	1	
12	14	33	female	4	
36	10	66	female	2	
24	14	66	female	1	Start 3
24	12	33	male	1	
24	18	33	female	1	
36	10	33	female	4	
36	10	33	male	2	
36	18	33	male	4	
36	16	33	male	3	
12	16	33	female	3	
36	14	33	female	3	
24	18	33	male	4	
12	10	100	female	1	
12	18	33	male	4	
24	20	33	male	1	
24	12	66	male	2	
36	16	33	female	1	Start 4
24	14	33	female	2	

24	10	100	female	3	
24	16	33	female	3	
24	10	33	female	4	
12	10	33	male	1	
36	12	66	female	1	
24	20	33	female	4	
12	12	33	male	1	
12	10	66	male	2	
24	12	100	female	1	
12	12	100	male	2	
36	10	100	male	3	
12	10	33	female	4	
12	10	66	female	3	
12	20	33	male	3	Start 5
36	14	66	male	3	
12	14	66	female	2	
36	14	100	male	4	
24	16	33	male	2	
12	14	33	male	3	
12	16	33	male	2	
24	10	100	male	2	
24	12	33	female	3	
36	20	33	male	4	
36	10	100	female	2	
36	12	33	male	1	
24	10	66	female	2	
12	14	100	female	4	

Task 2 Experimental Conditions

Streets	Percent Labeled	Point Size	Response	Map	Cross street	Start
36	33	12	female	1	6	Start 1
12	33	10	female	2	1	
24	33	12	male	4	1	
12	66	12	female	2	3	
12	66	10	male	1	2	
12	66	10	not labeled	4	3	
36	100	10	female	2	3	
24	100	10	female	4	3	
24	66	10	not labeled	1	4	
24	66	14	male	4	4	
12	33	12	not labeled	1	3	
24	33	14	male	2	1	
36	100	10	not there	2	8	
24	66	12	male	1	4	
24	100	14	male	1	3	
36	66	14	female	3	3	
36	33	14	male	4	1	
36	33	10	male	3	3	
12	33	10	male	3	3	
12	100	14	male	4	1	
24	33	12	not labeled	1	4	Start 2
12	66	12	not there	4	4	
36	33	12	not labeled	3	1	
36	66	12	male	2	6	
36	33	12	male	1	3	
36	33	14	not labeled	2	3	
24	33	10	male	1	4	
12	100	12	female	1	1	
12	66	14	not there	4	4	
24	33	10	female	3	3	
24	33	12	female	2	6	
24	66	12	female	3	1	
12	33	14	male	3	4	
36	33	14	not there	2	8	
24	66	14	not labeled	1	1	
36	100	12	not there	4	8	
36	66	12	female	4	1	
24	33	12	male	1	3	
36	33	14	female	3	6	
24	66	14	female	2	6	
24	33	14	not there	4	6	Start 3
12	66	10	female	2	4	
36	66	10	not labeled	2	3	
12	100	12	female	1	3	
24	100	10	female	2	6	

12	100	10	not there	1	4	
36	33	12	not there	2	8	
12	100	12	male	2	4	
12	33	10	not there	4	4	
36	66	10	not there	4	8	
36	100	12	male	3	3	
24	100	12	not there	3	6	
36	66	14	not there	2	8	
12	100	14	female	2	3	
24	33	10	not labeled	4	1	
36	100	14	male	1	8	
12	66	12	male	3	2	
24	66	12	not labeled	3	3	
12	33	14	not labeled	2	1	
12	66	14	not labeled	3	2	
36	100	14	female	4	1	Start 4
24	100	12	male	2	3	
12	100	14	not there	4	4	
12	33	12	male	4	1	
24	100	14	not there	3	6	
24	66	12	not there	4	6	
12	100	10	female	3	3	
24	100	14	female	1	1	
12	66	12	not labeled	2	1	
12	33	12	not there	4	4	
12	66	14	male	3	3	
36	33	10	not labeled	1	8	
12	33	12	female	3	2	
36	66	10	male	1	1	
36	100	10	male	1	1	
36	66	14	male	1	6	
24	100	12	female	2	1	
12	33	14	female	1	2	
24	66	10	male	2	3	
36	100	14	female	4	3	
24	33	14	not labeled	3	3	Start 5
24	33	14	female	2	4	
12	100	10	male	3	1	
36	66	12	not labeled	1	8	
24	100	10	male	4	1	
12	33	14	female	1	3	
24	66	10	not there	3	6	
36	33	10	male	4	6	
24	33	10	not there	3	6	
24	66	10	female	2	1	
36	66	14	not labeled	3	1	
36	100	12	female	3	1	
12	66	14	female	1	1	
36	66	12	female	4	3	

24	66	14	male	4	3
12	33	10	not labeled	2	2
12	66	10	male	1	1
36	33	10	female	4	1
36	66	10	female	3	6

Practice Task 3 Experimental Conditions

Slide #	Response	Start
10	not there	Start 1
5	not there	
9	behind	
3	right	
8	ahead	
9	behind	
6	right	
7	left	
10	not there	Start 2
6	right	
3	right	
2	left	
9	behind	
2	left	
9	behind	
1	ahead	
7	left	Start 3
10	not there	
8	ahead	
2	left	
4	behind	
5	not there	
6	right	
7	left	
5	not there	Start 4
8	ahead	
7	left	
1	ahead	
4	behind	
5	not there	
1	ahead	
3	right	
8	ahead	Start 5
2	left	
4	behind	
10	not there	
4	behind	
1	ahead	
6	right	
3	right	

Task 3 Experimental Conditions

Streets	Point Size	Percent Labeled	Response	Map	Name	Start
36	10	100	not there	3	Michael	Start 1
12	14	33	behind	3	Richard	
12	12	100	ahead	1	Roger	
36	12	33	ahead	1	Donna	
24	10	66	behind	3	Steven	
12	10	33	behind	4	William	
36	12	100	ahead	3	Stewart	
12	10	100	not there	1	Bernard	
36	12	66	ahead	4	Marvin	
24	12	100	ahead	2	Jeffrey	
36	12	33	behind	2	Jonathan	
36	14	33	behind	1	Benjamin	
12	12	66	side	2	Jeremy	
36	14	66	not there	2	Craig	
24	14	66	ahead	2	Veronica	
12	10	33	side	2	Gloria	
12	12	100	side	3	Kevin	
12	12	66	not there	4	Matthew	
36	14	66	behind	2	Wendy	
12	10	33	not there	2	Paula	
36	14	100	behind	3	Jennifer	
36	12	66	side	4	Beverly	
36	14	33	side	1	Pamela	Start 2
24	14	66	side	4	Elliot	
24	12	66	side	3	Denise	
12	12	100	behind	2	Dorothy	
24	10	66	not there	1	Bonnie	
24	14	100	behind	2	Lawrence	
36	12	33	not there	2	Michelle	
12	14	66	not there	4	Peter	
36	10	100	ahead	1	Deborah	
24	14	66	not there	1	Sheila	
36	10	33	side	4	Janet	
36	12	100	side	1	Gregory	
24	10	33	side	3	Wanda	
36	12	66	not there	2	Nicole	
12	14	66	ahead	1	Megan	
12	10	66	behind	2	Charlotte	
12	14	66	behind	4	Howard	
12	12	33	behind	4	Joseph	
24	12	100	side	4	Samuel	
24	12	66	behind	4	Betty	
24	10	33	not there	3	Duane	
24	12	100	behind	3	Phillip	Start 3
36	12	33	side	3	Albert	

12	10	66	not there	4	Bethany	
36	14	100	not there	4	Cynthia	
36	12	100	behind	4	Theresa	
24	12	33	behind	1	Dennis	
12	12	33	ahead	3	Bradley	
24	10	100	side	1	Angela	
24	12	33	not there	1	Norman	
36	14	100	side	2	Timothy	
36	12	100	not there	3	Florence	
12	10	100	behind	1	George	
36	14	66	side	1	Russell	
24	10	100	ahead	4	Karen	
36	12	66	behind	1	Caroline	
12	14	33	side	3	Emily	
24	14	66	behind	1	Melvin	
36	10	66	ahead	1	Curtis	
36	14	66	ahead	3	Margaret	
24	12	33	side	2	Rebecca	
36	10	33	behind	2	Ronald	
12	12	66	ahead	2	Melinda	
24	12	33	ahead	4	Henry	Start 4
24	14	33	behind	4	Edward	
12	10	66	ahead	3	Nancy	
12	10	33	ahead	1	Kenneth	
36	14	33	ahead	3	Patricia	
36	14	33	not there	4	Douglas	
24	14	100	not there	3	Walter	
24	10	33	ahead	2	Robert	
12	14	100	side	4	Virginia	
12	12	66	behind	3	Marie	
24	12	100	not there	2	Barbara	
24	14	100	side	1	Raymond	
36	10	100	behind	3	Clifford	
24	10	100	behind	2	Laura	
12	12	100	not there	1	Linda	
24	14	33	ahead	2	Victoria	
12	10	100	side	4	Suzanne	
36	10	66	not there	2	Thomas	
36	14	100	ahead	4	Charles	
24	10	33	behind	1	Colleen	
36	10	100	side	2	Douglas	
12	14	100	not there	2	Bruce	Start 5
12	14	100	behind	1	Louis	
24	10	66	ahead	4	David	
24	10	100	not there	2	Vincent	
12	14	33	ahead	1	Donald	
24	14	33	not there	3	Helen	
12	10	100	ahead	3	Andrew	
36	10	66	behind	4	Rhonda	

36	10	33	ahead	3	Andrea
12	12	33	side	1	Melissa
12	14	100	ahead	2	Grace
24	12	66	not there	1	Heidi
12	12	33	not there	4	Tammy
24	12	66	ahead	3	Jessica
24	14	33	side	4	Leonard
36	10	66	side	1	Nathan
36	10	33	not there	4	Sarah
24	10	66	side	4	Monica
12	10	66	side	3	Brian
12	14	33	not there	1	Julia
24	14	100	ahead	3	Elaine
12	14	66	side	3	Roxanne

Task 4 Experimental Conditions

Streets	Point Size	Percent Labeled	Response	Map	Start
24	12	66	female	3	Start 1
12	14	66	female	2	
12	10	66	female	3	
36	14	100	male	4	
24	10	100	female	3	
36	10	100	male	3	Start 2
24	12	33	male	1	
36	10	66	female	2	
36	14	66	female	2	
36	12	66	male	4	
12	10	33	male	1	
12	14	33	male	3	Start 3
24	10	66	male	3	
24	14	100	female	4	
36	12	100	female	2	
12	12	66	male	1	
24	12	100	male	3	Start 4
36	12	33	female	2	
12	12	100	female	1	
12	14	100	male	3	
24	10	33	female	4	
36	14	33	male	4	
36	10	33	male	2	Start 5
12	10	100	male	4	
24	14	33	female	2	
24	14	66	male	4	
12	12	33	female	2	

APPENDIX F - Summary of Task Errors and Outliers

All error trials and outliers for Task 1 were replaced by the trial with the same map characteristics (number of streets, point size, percent labeled) within the same subject. A total of 4 trials were replaced in the data set: 3 error trials and 1 outlier.

Task 1

Subject Number	Subject Mean ± SD	Response Time (ms)	Replacement Time (ms)	Comments
7 (OF)	1775 ± 520 *	15642	1319	Error trial. Subject ran off road and did not look back to the map in a reasonable amount of time.
8 (OF)	2153 ± 925 *	11578	2249	Error trial. Subject ran off road and did not look back to the map in a reasonable amount of time.
10 (OM)	2466 ± 1987 *	10487	2396	Error trial. Subject did not notice that a map had come up.
10 (OM)	2466 ± 1987 *	13246	7251	Trial was well beyond the 3σ time for both the subject and older men.

* subject mean was calculated after the error trial was replaced.

All error trials and outliers for Task 2 were replaced by the cell mean of the exact same trial in the same age/gender group. In other words, if an outlier occurred on a trial for a young man, then the average of the exact same trial for the other four young men would replace the error trial. A total of 15 trials were replaced: 2 error trials and 13 outliers.

Task 2

Subject Number	Characteristics		Response Time (ms)	Replcmt. Time (ms)	Comments
	X-street	Resp.			
1 (OF)	6	female	21033	5241	Beyond 3σ time on trials with same characteristics for older subjects (18589 ms).
1 (OF)			14467	4025	Error trial. The response button was not functioning properly.
1 (OF)	1	male	11869	2877	Beyond 3σ time on trials with same characteristics for older subjects (6235 ms).
6 (YF)	6	female	23143	3605	Beyond 3σ time on trials with same characteristics for young subjects (15713 ms).
8 (OF)	3	male	18912	2708	Beyond 3σ time on trials with same characteristics for older subjects (10553 ms).
8 (OF)	4	not there	10860	3234	Beyond 3σ time on trials with same characteristics for older subjects (8212 ms).
8 (OF)	6	not there	24194	4640	Beyond 3σ time on trials with same characteristics for older subjects (19612 ms).
8 (OF)	6	not there	24079	5106	Same as above.
8 (OF)	6	female	25000	5241	Same 3σ time as for subject 1.
10 (OM)	3	not labeled	13678	3370	Beyond 3σ time on trials with same characteristics for older subjects (9561 ms).
10 (OM)	8	male	25000	5624	Not beyond 3σ time on trials with same characteristics for older subjects (26083 ms), but time reached maximum and probably would have been beyond 3σ time..
18 (YM)	6	female	22428	2990	Same 3σ time as for subject 6.
19 (YF)			8190	1681	Error trial. The shutter on the projector was not open.

All error trials and outliers for Task 3 were replaced by the cell mean of the exact same trial in the same age/gender group. A total of 11 trials were replaced: 2 error trials and 9 outliers.

Task 3

Subject Number	Subject Mean ± SD	Response Time (ms)	Replcmt. Time (ms)	Comments
1 (OF)	7257 ± 4325	23188	7183	Trial beyond the 3σ time for both the subject and older women (15744 ms).
2 (OM)	8333 ± 4493	25000	14913	Trial beyond the 3σ time for both the subject and older men (20491 ms).
2 (OM)	8333 ± 4493	23164	14616	Same as above.
2 (OM)	8333 ± 4493	22567	14857	Same as above.
5 (OM)	8191 ± 4149	23619	6777	Same as above.
6 (YF)	5558 ± 3318	20636	9155	Trial beyond the 3σ time for both the subject and young women (12165 ms).
8 (OF)	7060 ± 4245	23213	7417	This trial was beyond the 3σ time for both the subject and older women.
10 (OM)	7952 ± 4500	25000	14826	This trial was beyond the 3σ time for both the subject and older men.
12 (YM)	2918 ± 1372 *	136	1976	Error trial. Response time too fast.
15 (YF)	4294 ± 2633	16901	9155	This trial was beyond the 3σ time for both the subject and young women.
18 (YM)	5636 ± 3462 *	4210	2524	Error trial. Experimenter spoke incorrect name to subject, thus invalidating the trial.

* subject mean was calculated after the error trial was replaced.

All error trials and outliers for Task 4 were replaced by the cell mean of the exact same trial in the same age/gender group and the same block group. In other words, if an outlier occurred on a trial for a young man, then the average of the exact same trial for the other young men who shared the same block pattern would replace the error trial. A total of 7 trials were replaced: 6 error trials and 1 outlier.

Task 4

Subject Number	Subject Mean ± SD	Response Time (ms)	Replcmt. Time (ms)	Comments
1 (OF)	2269 ± 669 *	11920	1561	Error trial. Temporarily forgot instructions.
4 (OF)	1646 ± 673	5967	2895	Trial beyond the 3σ time for both the subject and older women (3981 ms).
6 (YF)	1368 ± 573	5097	---	Trial beyond the 3σ time for both the subject and young women (2361 ms). However, it was the first trial that the subject saw (in the low position), and is considered a valid data point.
8 (OF)	1835 ± 714 *	25000	1771	Error trial. Image in wrong position.
10 (OM)	2636 ± 1123 *	5063	979	Error trial. Image out of focus.
10 (OM)	2636 ± 1123 *	23222	2268	Error trial. Image out of focus.
13 (YM)	1718 ± 486 *	13788	1082	Error trial. Image out of focus.
19 (YF)	1229 ± 222 *	13459	1052	Error trial. Shutter not open.

* subject mean was calculated after the error trial(s) were replaced.

APPENDIX G - Task 1 Response-Time ANOVA Table

Source	dF	Sum of Squares	Mean Square	F-value	P-value
Age	1	1.57E8	1.57E8	48.192	.0001
Gender	1	6.60E6	6.60E6	2.030	.1734
Age * Gender	1	3.30E6	3.30E6	1.014	.3288
Subject(Group)	16	5.20E7	3.25E6		
#streets	2	6.53E6	3.27E6	12.946	.0001
#streets * Age	2	3.26E6	1.63E6	6.461	.0044
#streets * Subject(Group)	32	8.07E6	2.52E5		
point size	2	2.79E7	1.39E7	34.991	.0001
point size * Age	2	2.08E7	1.04E7	26.141	.0001
point size * Gender	2	3.11E6	1.55E6	3.900	.0305
point size * Age * Gender	2	2.86E6	1.43E6	3.588	.0393
point size * Subject(Group)	32	1.28E7	3.99E5		
%labeled	2	2.91E6	1.45E6	3.770	.0339
%labeled * Age	2	7.93E4	3.96E4	0.103	.9026
%labeled * Subject(Group)	32	1.23E7	3.85E5		
CR	1	3.46E4	3.46E4	0.123	.7303
CR * Age	1	3.11E5	3.11E5	1.108	.3082
CR * Subject(Group)	16	4.50E6	2.81E5		
#streets * point size	4	6.58E6	1.64E6	4.588	.0026
#streets * point size * Age	4	7.89E6	1.97E6	5.503	.0007
#streets * point size * Subject(Group)	64	2.29E7	3.58E5		
#streets * %labeled	4	4.78E5	1.19E5	0.442	.7779
#streets * %labeled * Age	4	1.13E5	2.83E4	0.105	.9804
#streets * %labeled * Subject(Group)	64	1.73E7	2.70E5		
point size * %labeled	4	5.19E6	1.30E6	4.764	.0020
point size * %labeled * Age	4	9.20E5	2.30E5	0.844	.5026
point size * %labeled * Subject(Group)	64	1.74E7	2.73E5		
#streets * CR	2	2.39E6	1.19E6	5.916	.0065
#streets * CR * Age	2	1.85E6	9.24E5	4.578	.0178
#streets * CR * Gender	2	1.10E6	5.51E5	2.730	.0804
#streets * CR * Subject(Group)	32	6.46E6	2.02E5		
point size * CR	2	1.90E6	9.49E5	3.778	.0337
point size * CR * Age	2	1.95E6	9.73E5	3.874	.0311
point size * CR * Subject(Group)	32	8.04E6	2.51E5		
%labeled * CR	2	1.19E6	5.96E5	2.896	.0698
%labeled * CR * Age	2	5.89E4	2.94E4	0.143	.8674
%labeled * CR * Gender	2	1.02E6	5.11E5	2.483	.0994
%labeled * CR * Age * Gender	2	9.49E5	4.75E5	2.305	.1161
%labeled * CR * Subject(Group)	32	6.59E6	2.06E5		

Note: Many insignificant gender and age*gender interactions with each factor were omitted from this summary ANOVA.

APPENDIX H - Task 1 Response-Time ANOVA Table (additional point sizes)

Source	dF	Sum of Squares	Mean Square	F-value	P-value
Age	1	2.89E7	2.89E7	1.272	.2669
Gender	1	1.11E6	1.11E6	.049	.8266
Age * Gender	1	2.30E5	2.3E5	.010	.9205
Subject(Group)	36	8.19E8	2.27E7		
Streets	2	8.05E5	4.03E5	2.531	.0867
Streets * Age	2	1.97E5	9.84E4	.619	.5416
Streets * Gender	2	5.44E5	2.72E5	1.710	.1882
Streets * Age * Gender	2	5.78E5	2.89E5	1.816	.1701
Streets * Subject(Group)	72	1.15E7	1.59E5		
Point size	5	1.31E7	2.62E6	9.676	.0001
Point size * Age	5	8.36E6	1.67E6	6.180	.0001
Point size * Gender	5	2.77E6	5.54E5	2.048	.0741
Point size * Age * Gender	5	2.18E6	4.36E5	1.611	.1594
Point size * Subject(Group)	180	4.87E7	2.71E5		
CR	1	9.06E3	9.06E3	.138	.7123
CR * Age	1	1.68E5	1.68E5	2.570	.1176
CR * Gender	1	2.73E4	2.73E4	.416	.5231
CR * Age * Gender	1	8.87E4	8.87E4	1.353	.2524
CR * Subject(Group)	36	2.36E6	6.55E4		
Streets * Point size	10	4.12E6	4.11E5	3.187	.0006
Streets * Point size * Age	10	3.48E6	3.48E5	2.692	.0034
Streets * Point size * Gender	10	1.38E6	1.38E5	1.066	.3880
Streets * Point size * Age * Gender	10	1.27E6	1.27E5	.983	.4580
Streets * Point size * Subject(Group)	360	4.65E7	1.29E5		
Streets * CR	2	5.45E4	2.72E4	.383	.6829
Streets * CR * Age	2	5.28E4	2.64E4	.372	.6906
Streets * CR * Gender	2	5.05E5	2.52E5	3.554	.0337
Streets * CR * Age * Gender	2	4.17E5	2.09E5	2.937	.0594
Streets * CR * Subject(Group)	72	5.11E6	7.1E4		
Point size * CR	5	3.55E5	7.09E4	1.071	.3781
Point size * CR * Age	5	1.26E5	2.51E4	.379	.8627
Point size * CR * Gender	5	2.74E5	5.48E4	.828	.5310
Point size * CR * Age * Gender	5	3.70E5	7.4E4	1.117	.3527
Point size * CR * Subject(Group)	180	1.19E7	6.62E4		
Streets * Point size * CR	10	1.83E6	1.83E5	2.840	.0021
Streets * Point size * CR * Age	10	3.44E5	3.44E4	.534	.8660
Streets * Point size * CR * Gender	10	4.22E5	4.22E4	.655	.7662
Streets * Point size * CR * Age * Gender	10	4.57E5	4.57E4	.709	.7160
Streets * Point size * CR * Subject (Group)	360	2.32E7	6.44E4		

APPENDIX I - Task 2 Error ANOVA Table

Source	dF	Sum of Squares	Mean Square	F-value	P-value
Age	1	48000.0	48000.0	46.7	.0001
Gender	1	4481.5	4481.5	4.4	.0531
Age * Gender	1	333.3	333.3	0.3	.5769
Subject(Group)	16	16444.4	1027.8		
#streets	2	12722.2	6361.1	5.8	.0073
#streets * Age	2	2055.6	1027.8	0.9	.4046
#streets * Subject(Group)	32	35333.3	1104.2		
point size	2	1166.7	583.3	0.6	.5382
point size * Age	2	3500.0	1750.0	1.9	.1668
point size * Subject(Group)	32	29555.6	923.6		
%labeled	2	2000.0	1000.0	1.5	.2281
%labeled * Age	2	666.7	333.3	0.5	.6017
%labeled * Subject(Group)	32	20666.7	645.8		
cross-street	1	3000.0	3000.0	1.1	.3038
cross-street * Age	1	37.0	37.0	0.01	.9075
cross-street * Subject(Group)	16	42518.5	2657.4		
#streets * point size	4	8944.4	2236.1	3.3	.0160
#streets * point size * Age	4	8611.1	2152.8	3.2	.0191
#streets * point size * Subject(Group)	64	43333.3	677.1		
#streets * %labeled	4	10777.8	2694.4	3.8	.0074
#streets * %labeled * Age	4	1444.4	361.1	0.5	.7250
#streets * %labeled * Subject(Group)	64	44888.9	701.4		
point size * %labeled	4	10166.7	2541.7	2.3	.0639
point size * %labeled * Age	4	9166.7	2291.7	2.1	.0891
point size * %labeled * Subject(Group)	64	69333.3	1083.3		
#streets * cross-street	2	2722.2	1361.1	1.2	.3020
#streets * cross-street * Age	2	796.3	398.1	0.4	.6980
#streets * cross-street * Gender	2	8685.2	4342.6	4.0	.0289
#streets * cross-street * Age * Gender	2	4240.7	2120.4	1.9	.1607
#streets * cross-street * Subject(Group)	32	35037.0	1094.9		
point size * cross-street	2	1722.2	861.1	1.0	.3781
point size * cross-street * Age	2	2351.9	1175.9	1.4	.2688
point size * cross-street * Subject(Group)	32	27481.5	858.8		
%labeled * cross-street	2	8000.0	4000.0	5.3	.0107
%labeled * cross-street * Age	2	3851.9	1925.9	2.5	.0956
%labeled * cross-street * Subject(Group)	32	24370.4	761.6		

Note: Many insignificant gender and age*gender interactions with each factor were omitted from this summary Error ANOVA.

APPENDIX J - Task 2 Response-Time ANOVA Table

Source	dF	Sum of Squares	Mean Square	F-value	P-value
Age	1	2.46E8	2.46E8	17.618	.0007
Gender	1	1.08E5	1.08E5	0.008	.9310
Age * Gender	1	1.14E7	1.14E7	0.812	.3808
Subject(Group)	16	2.24E8	1.40E7		
#streets	2	2.55E7	1.27E7	16.042	.0001
#streets * Age	2	3.36E6	1.68E6	2.113	.1375
#streets * Subject(Group)	32	2.54E7	7.94E5		
point size	2	4.38E5	2.19E5	0.153	.8591
point size * Age	2	6.15E5	3.08E5	0.214	.8082
point size * Subject(Group)	32	4.59E7	1.43E6		
%labeled	2	3.92E6	1.96E6	2.303	.1163
%labeled * Age	2	6.53E6	3.27E6	3.838	.0321
%labeled * Subject(Group)	32	2.72E7	8.51E5		
cross-street	1	3.53E8	3.53E8	67.376	.0001
cross-street * Age	1	4.8E6	4.8E6	0.915	.3531
cross-street * Subject(Group)	16	8.39E7	5.25E6		
#streets * point size	4	1.23E6	3.07E5	0.299	.8778
#streets * point size * Age	4	1.21E7	3.02E6	2.940	.0270
#streets * point size * Subject(Group)	64	6.58E7	1.03E6		
#streets * %labeled	4	1.36E6	3.41E5	0.378	.8233
#streets * %labeled * Age	4	6.56E5	1.64E5	0.182	.9468
#streets * %labeled * Subject(Group)	64	5.76E7	9E5		
point size * %labeled	4	3.41E6	8.53E5	0.966	.4324
point size * %labeled * Age	4	1.91E6	4.78E5	0.542	.7056
point size * %labeled * Subject(Group)	64	5.65E7	8.83E5		
#streets * cross-street	2	1.22E7	6.12E6	7.921	.0016
#streets * cross-street * Age	2	2.28E6	1.14E6	1.473	.2444
#streets * cross-street * Subject(Group)	32	2.47E7	7.73E5		
point size * cross-street	2	2.94E6	1.47E6	0.959	.3941
point size * cross-street * Age	2	2.94E5	1.47E5	0.096	.9089
point size * cross-street * Subject(Group)	32	4.9E7	1.53E6		
%labeled * cross-street	2	1.29E7	6.44E6	12.325	.0001
%labeled * cross-street * Age	2	3.28E6	1.64E6	3.142	.0568
%labeled * cross-street * Subject(Group)	32	1.67E7	5.23E5		

Note: Interactions between each within-subject factor and the 2 between-subject factors, gender and age * gender, were removed as none were significant.

APPENDIX K - Task 3 Error ANOVA Table

Source	dF	Sum of Squares	Mean Square	F-value	P-value
Age	1	34240.7	34240.7	8.595	.0098
Gender	1	166.7	166.7	0.042	.8405
Age * Gender	1	463.0	463.0	0.116	.7376
Subject(Group)	16	63740.7	3983.8		
#streets	2	36953.7	18476.9	26.966	.0001
#streets * Age	2	8231.5	4115.7	6.007	.0061
#streets * Gender	2	1194.4	597.2	0.872	.4280
#streets * Age * Gender	2	4287.0	2143.5	3.128	.0574
#streets * Subject(Group)	32	21925.9	685.2		
point size	2	3814.8	1907.4	2.551	.0938
point size * Age	2	703.7	351.9	0.471	.6289
point size * Subject(Group)	32	23925.9	747.7		
%labeled	2	22953.7	11476.9	16.582	.0001
%labeled * Age	2	1287.0	643.5	0.930	.4050
%labeled * Subject(Group)	32	22148.1	692.1		
location	3	93351.9	31117.3	19.286	.0001
location * Age	3	11129.6	3709.9	2.299	.0892
location * Subject(Group)	48	77444.4	1613.4		
#streets * point size	4	5629.6	1407.4	1.569	.1933
#streets * point size * Age	4	3407.4	851.9	0.950	.4413
#streets * point size * Subject(Group)	64	57407.4	897.0		
#streets * %labeled	4	12157.4	3039.4	3.287	.0163
#streets * %labeled * Age	4	9824.1	2456.0	2.656	.0408
#streets * %labeled * Subject(Group)	64	59185.2	924.8		
point size * %labeled	4	1296.3	324.1	0.403	.8061
point size * %labeled * Age	4	2851.9	713.0	0.886	.4777
point size * %labeled * Gender	4	6555.6	1638.9	2.036	.0998
point size * %labeled * Age * Gender	4	3518.5	879.6	1.093	.3678
point size * %labeled * Subject(Group)	64	51518.5	805.0		
#streets * location	6	21453.7	3575.6	4.439	.0005
#streets * location * Age	6	7731.5	1288.6	1.600	.1556
#streets * location * Subject(Group)	96	77333.3	805.6		
point size * location	6	8259.3	1376.5	1.553	.1695
point size * location * Age	6	4259.3	709.9	0.801	.5717
point size * location * Subject(Group)	96	85111.1	886.6		
%labeled * location	6	8009.3	1334.9	1.326	.2532
%labeled * location * Age	6	8342.6	1390.4	1.381	.2301
%labeled * location * Subject(Group)	96	96666.7	1006.9		

Note: Many insignificant gender and age*gender interactions with each factor were omitted from this summary Error ANOVA.

APPENDIX L - Task 3 Response-Time ANOVA Table

Source	dF	Sum of Squares	Mean Square	F-value	P-value
Age	1	3.85E9	3.85E9	34.172	.0001
Gender	1	2.54E8	2.54E8	2.251	.1530
Age * Gender	1	4.29E8	4.29E8	3.804	.0689
Subject(Group)	16	1.80E9	1.13E8		
#streets	2	3.24E9	1.62E9	149.417	.0001
#streets * Age	2	1.42E8	7.12E7	6.569	.0041
#streets * Subject(Group)	32	3.47E8	1.08E7		
point size	2	1.57E8	7.86E7	13.416	.0001
point size * Age	2	2.38E7	1.19E7	2.029	.1480
point size * Gender	2	1.50E7	7.48E6	1.277	.2928
point size * Age * Gender	2	4.35E7	2.18E7	3.714	.0355
point size * Subject(Group)	32	1.88E8	5.86E6		
%labeled	2	2.63E9	1.31E9	180.947	.0001
%labeled * Age	2	1.09E8	5.45E7	7.512	.0021
%labeled * Gender	2	4.46E7	2.23E7	3.070	.0603
%labeled * Age * Gender	2	3.68E7	1.84E7	2.535	.0951
%labeled * Subject(Group)	32	2.32E8	7.26E6		
location	3	1.46E9	4.87E8	38.037	.0001
location * Age	3	4.67E7	1.56E7	1.215	.3146
location * Subject(Group)	48	6.15E8	1.28E7		
#streets * point size	4	3.63E7	9.08E6	1.769	.1459
#streets * point size * Age	4	2.55E6	6.37E5	0.124	.9732
#streets * point size * Subject(Group)	64	3.28E8	5.13E6		
#streets * %labeled	4	3.80E8	9.50E7	25.958	.0001
#streets * %labeled * Age	4	2.56E6	6.41E5	0.175	.9504
#streets * %labeled * Subject(Group)	64	2.34E8	3.66E6		
point size * %labeled	4	3.32E7	8.31E6	2.684	.0391
point size * %labeled * Age	4	8.90E6	2.23E6	0.719	.5821
point size * %labeled * Subject(Group)	64	1.98E8	3.09E6		
#streets * location	6	3.88E8	6.46E7	17.479	.0001
#streets * location * Age	6	3.05E7	5.08E6	1.373	.2331
#streets * location * Subject(Group)	96	3.55E8	3.70E6		
point size * location	6	8.94E7	1.49E7	3.968	.0014
point size * location * Age	6	3.58E7	5.96E6	1.587	.1592
point size * location * Subject(Group)	96	3.61E8	3.76E6		
%labeled * location	6	4.11E8	6.85E7	20.533	.0001
%labeled * location * Age	6	2.91E7	4.85E6	1.456	.2017
%labeled * location * Subject(Group)	96	3.20E8	3.33E6		

Note: The insignificant gender and age*gender interactions with each factor were omitted from this summary ANOVA.

APPENDIX M - Task 4 Response-Time ANOVA Table

Source	dF	Sum of Squares	Mean Square	F-value	P-value
Age	1	1.11E8	1.11E8	18.126	.0007
Gender	1	6.34E6	6.34E6	1.036	.3248
Age * Gender	1	1.62E6	1.62E6	0.265	.6139
Block Sequence	1	1.13E6	1.13E6	0.184	.6738
Subject(Group)	15	9.18E7	6.12E6		
Position	1	6.83E6	6.83E6	16.725	.0010
Position * Age	1	3.33E5	3.33E5	0.816	.3806
Position * Block Sequence	1	3.63E6	3.63E6	8.901	.0093
Position * Subject(Group)	15	6.12E6	4.08E5		
#streets	2	5.91E6	2.96E6	7.995	.0016
#streets * Age	2	1.68E6	8.39E5	2.270	.1208
#streets * Subject(Group)	30	1.11E7	3.70E5		
point size	2	1.49E7	7.47E6	16.223	.0001
point size * Age	2	7.83E6	3.91E6	8.504	.0012
point size * Block Sequence	2	2.40E6	1.20E6	2.607	.0904
point size * Subject(Group)	30	1.38E7	4.60E5		
%labeled	2	7.07E6	3.54E6	7.659	.0021
%labeled * Age	2	3.57E6	1.78E6	3.863	.0322
%labeled * Gender	2	3.19E6	1.60E6	3.457	.0446
%labeled * Subject(Group)	30	1.38E7	4.62E5		
Position * #streets	2	2.64E5	1.32E5	0.528	.5953
Position * #streets * Age	2	3.61E4	1.80E4	0.072	.9306
Position * #streets * Subject(Group)	30	7.50E6	2.50E5		
Position * point size	2	4.26E5	2.13E5	0.931	.4053
Position * point size * Age	2	5.31E5	2.65E5	1.161	.3269
Position * point size * Block Sequence	2	1.22E6	6.12E5	2.678	.0851
Position * point size * Subject(Group)	30	6.86E6	2.29E5		
#streets * point size	4	8.74E5	2.18E5	0.716	.5842
#streets * point size * Age	4	1.25E6	3.11E5	1.021	.4036
#streets * point size * Subject(Group)	60	1.83E7	3.05E5		
Position * %labeled	2	6.84E5	3.42E5	0.861	.4331
Position * %labeled * Age	2	1.65E6	8.23E5	2.069	.1439
Position * %labeled * Subject(Group)	30	1.19E7	3.98E5		
#streets * %labeled	4	2.04E6	5.10E5	1.476	.2207
#streets * %labeled * Age	4	1.56E6	3.91E5	1.132	.3503
#streets * %labeled * Subject(Group)	60	2.07E7	3.46E5		
point size * %labeled	4	3.23E6	8.07E5	3.387	.0145
point size * %labeled * Age	4	1.98E6	4.96E5	2.079	.0947
point size * %labeled * Subject(Group)	60	1.43E7	2.38E5		

Note: Many insignificant gender, age*gender, and block sequence interactions with each factor were omitted from this summary ANOVA.

APPENDIX N - Task-Comparison ANOVA Table

Source	dF	Sum of Squares	Mean Square	F-value	P-value
Task	1	3.75E5	3.75E5	0.488	.4949
Task * Age	1	1.61E6	1.61E6	2.100	.1666
Task * Gender	1	4.07E3	4.07E3	0.005	.9429
Task * Age * Gender	1	4.40E5	4.40E5	0.573	.4602
Task * Subject(Group)	16	1.23E7	7.68E5		
Task * #streets	2	3.20E5	1.60E5	1.237	.3038
Task * #streets * Age	2	2.65E5	1.33E5	1.026	.3700
Task * #streets * Gender	2	3.24E5	1.62E5	1.253	.2993
Task * #streets * Age * Gender	2	5.85E5	2.92E5	2.264	.1204
Task * #streets * Subject(Group)	32	4.13E6	1.29E5		
Task * point size	2	4.70E5	2.35E5	1.672	.2038
Task * point size * Age	2	1.14E6	5.69E5	4.047	.0271
Task * point size * Gender	2	3.09E4	1.55E4	0.110	.8961
Task * point size * Age * Gender	2	2.04E4	1.02E4	0.073	.9301
Task * point size * Subject(Group)	32	4.50E6	1.41E5		
Task * %labeled	2	2.21E5	1.10E5	0.583	.5638
Task * %labeled * Age	2	2.85E5	1.42E5	0.752	.4796
Task * %labeled * Gender	2	1.14E6	5.72E5	3.022	.0628
Task * %labeled * Age * Gender	2	2.17E5	1.09E5	0.574	.5692
Task * %labeled * Subject(Group)	32	6.06E6	1.89E5		
Task * #streets * point size	4	1.10E6	2.75E5	2.336	.0648
Task * #streets * point size * Age	4	1.33E6	3.32E5	2.813	.0324
Task * #streets * point size * Gender	4	9.94E5	2.49E5	2.109	.0899
Task * #streets * point size * Age * Gender	4	1.18E6	2.96E5	2.509	.0504
Task * #streets * point size * Subject(Group)	64	7.54E6	1.18E5		
Task * #streets * %labeled	4	9.93E5	2.48E5	0.830	.5108
Task * #streets * %labeled * Age	4	3.81E5	9.53E4	0.319	.8644
Task * #streets * %labeled * Gender	4	1.25E6	3.11E5	1.042	.3927
Task * #streets * %labeled * Age * Gender	4	6.11E5	1.53E5	0.511	.7279
Task * #streets * %labeled * Subject(Group)	64	1.91E7	2.99E5		
Task * point size * %labeled	4	6.76E5	1.69E5	1.053	.3873
Task * point size * %labeled * Age	4	7.71E4	1.93E4	0.120	.9749
Task * point size * %labeled * Gender	4	7.34E5	1.84E5	1.142	.3447
Task * point size * %labeled * Age * Gender	4	7.91E5	1.98E5	1.230	.3068
Task * point size * %labeled * Subject(Group)	64	1.03E7	1.61E5		