AUTOMOBILE NAVIGATION METHODS: EFFECTIVENESS, EFFICIENCY, AND STRATEGY

by

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(ABSTRACT)

A study was performed to evaluate the effectiveness, efficiency, and strategy associated with three navigation methods: memorized route, conventional paper map, and a moving-map navigational display (the navigator). Thirty-two driver-subjects of both genders, and wide ranges of age (18-73) and driving experience (2,000 to 40,000 miles per year) navigated along public roadways for this research using a specially instrumented automobile. A variety of different roadway conditions were also used for this research including limited access four-lane highways, two-lane state routes, and city streets. In addition, the research was conducted under conditions of both light and moderate traffic densities. Measures taken include eye movement, navigation effectiveness, and driving performance measures. Results showed that the paper map took longer to study at the beginning of a run than the navigator. Even with this handicap, the total time taken when using the paper map was not significantly different from the time taken to use the navigator. Also, there were no differences in the directness or quality of routes selected when using either the paper map or the navigator to navigate. These findings were a result of the strategies adopted in the use of the various methods of navigation. During the initial study phase the paper map was essentially used to plan the entire route from start to finish. After the initial phase, the map was used only as an occasional reference. In contrast, effective use of the navigator could only be accomplished by repetitively glancing at the display to acquire important information as it was updated and presented. As a result, subjects spent

more driving time glancing to the navigator than the paper map, and it substantially drew the subjects' gaze away from the driving task relative to the norm established in the memorized route condition, as well as in comparison to the paper map. Still, driving performance did not greatly change as a function of navigation method indicating that the additional visual attentional demand associated with the navigator was drawn primarily from spare driver resources. It is also very likely that the novelty of the navigator was responsible for some portion of the glance time spent on it.

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INTRODUCTION

Many complex behaviors are involved in the driving task; this requires that human factors issues be given prime consideration in the design and analysis of the car/driver interface (Forbes, 1972). Specific human factors issues are display/control compatibility with driver stereotypes, and insuring that the physical and mental workloads imposed by system demands are not too great with regard to fatigue and safety. Clearly any novel system should be as efficient, effective, and safe as the corresponding conventional one.

The driving task can be classified into primary, secondary, and tertiary tasks or behaviors. The primary driving tasks are tracking of the road or a leading car, speed maintenance, and gear shifting.

Important parts of the driving task not directly associated with the operation of the vehicle itself may be considered secondary driving tasks. These include monitoring the instrument cluster to determine vehicle condition (e.g., speed, amount of fuel remaining, and other subsystem checks); monitoring the environment for regular and unusual traffic conditions, pedestrians, obstacles, traffic lights and signs; and navigation.

In addition to the primary and secondary tasks, time-sharing must be accomplished with regard to many other tertiary tasks or behaviors also exhibited in the driving environment. These are behaviors commonly exhibited while driving that do not directly or indirectly contribute to the driving task. Included in this category are such things as stereo system manipulation, listening to recorded or broadcast programming, manipulation of the climate control system, sightseeing, engaging in conversations with passengers, etc.

These sensorimotor, perceptual, mediational, and communications tasks must be integrated and accomplished in an effective and efficient manner. Further, most experienced drivers perform the primary and secondary tasks in automatic fashion devoting little active attention to the driving task itself (Senders, Kristofferson, Levison, Dietrich, and Ward 1966; Zwahlen, 1981). This fact highlights the importance of good design principles in the implementation of all onboard control/display panels.

The driving scenario, as described, has existed relatively unchanged for many years. However, recent innovations in microcomputer and display technology have greatly broadened the scope and fundamentally changed the manner in which information can be displayed to the driver. Devices such as Light Emitting Diode (LED), Liquid Crystal (LCD), gas discharge, plasma, vacuum-flourescent, electro-luminescent, and Cathode Ray Tube (CRT) displays allow for the centrally located presentation of complex information regarding such diverse systems as the stereo/radio, the climate control, and the trip monitor computer.

An obvious question that arises with regard to this new technology is how well does the human operator adapt to the new formats and types of information? There are contradictory data, and each new feature must be evaluated based on its own unique merits and drawbacks in each given situation. For example Ishii (1980) found a digital speedometer to produce shorter recognition times than an analog display when both were calibrated to one km/hr. However, when the analog display was uncluttered by having its smallest scale markings removed, no difference was found between the two displays.

A study was recently conducted to assess the human factors issues associated with a system which typifies this trend of using microcomputer and flexible display technology to present a central, integrated control/display configuration to the driver. Monty, Snyder, Farley, Donahoo, and Baggen (1985) compared a dashboard CRT/Touch Entry Device (TED) to a conventional control/display layout. The CRT/TED performed trip monitor, climate control, radio, and engine monitoring functions. None of these functions were related to navigation. Results from this study indicated that the CRT/TED units tested produced longer task completion times and required a greater number of glances to the display than the corresponding conventional systems. Thus even though a new control/display system is feasible from an engineering standpoint, it may not be the best system in terms of efficiency.

Among the newest innovations in information display are onboard navigational displays. These present dynamically updated, graphical map information to the driver. The map display is updated based upon the location of the vehicle in the mapped area, and the specific location of the vehicle on the map is also shown. There is research to support the notion that drivers in unfamiliar environments should be given guidance aids. Mourant and Rockwell (1970) found that drivers in unfamiliar areas had more dispersed gaze patterns than drivers who were familiar with the experimental route. This suggests that drivers unfamiliar with an area spent more time searching for navigation cues (e.g., landmarks and street signs), and less time attending to the primary driving task. In a survey of mobile telephone users, reading a map while driving was rated as the most dangerous of a group of tasks including tuning the radio, using a dictating machine, and writing something down, among others (Smith, 1978).

There are many concurrent efforts on the part of U.S. and foreign automobile manufacturers to devise such guidance aids. In the 1970s researchers in the United States experimented with navigation systems utilizing radio transmissions from a central installation where there was usually a host computer (Totani, Kato, and Muramoto, 1983). Ford Motor Company is in the process of planning a global positioning satellite navigation system (Yun, 1985). A prototype navigation system has been developed by Honda Research and Development engineers utilizing a precision gas-rate gyro sensor and a distance sensor. The updated car position is displayed on a CRT screen (Tagami, Takahashi, and Takahashi, 1983). Nissan Motor Co. has developed a prototype Driver Guide System which uses terrestrial magnetism to locate the car in the mapped area. The Driver Guide additionally gives information on direction and distance to destination (Mitamura, Chugo, and Senoo, 1983).

For future directions in the field of automotive navigation, the Japanese developers have outlined a national project to develop a system which not only displays a moving-map with updated vehicle position information but also provides information on which route to take based on traffic and road conditions. Information of this sort would be calculated and transmitted from a host computer in a fixed installation; the results of this effort have not yet been made public (Totani et al., 1983).

One navigation device is operational and presently on the market. The Etak Navigator (the navigator) utilizes an onboard computer and augmented dead reckoning to locate the vehicle in the mapped area (Etak, 1985a, b). Once the current location is programmed into the system, magnetic sensors are used to derive precise information from the angle and rotation of the wheels as to vehicle location and heading. This is known as dead reckoning, and it is augmented with stored information about the roadways in the local area. The map information for a given area is stored on special cassette tapes. A typical effect of augmentation would occur in the following scenario. Based on a slight accumulated error derived from the wheel sensors, the navigator indicates that the vehicle is slightly off, but parallel to the actual roadway on which the vehicle is travelling. Augmentation is effected when the navigator's computer recognizes this fact and updates the location of the vehicle onto the correct roadway.

There are two main pieces of information displayed on the navigator's display: (1) a map of the area surrounding the current location of the vehicle, and (2) a marker representing the current location of the vehicle on the map. In its standard operating mode the display has a "heading-up" orientation; that is, the marker representing the current location of the vehicle remains stationary relative to the screen. The map rotates and moves past the current location marker such that the actual heading of the vehicle is always represented as up on the display.

The Etak Navigator also has a zoom in/zoom out feature which allows the driver to view the mapped area in greater or less detail depending on which scale level is selected. It is important to understand that one can only zoom in or out in the area around the current location; that is the current location remains essentially centered on the map. It is not possible to zoom in or out around any other focal point (e.g., the programmed destination). There are nine scales, each indicating the represented distance from the current location marker to the top of the map. The scales are (in miles) 40, 20, 10, 5, 2, 1, 1/2, 1/4, and 1/8. Only the most major highways are shown on the 40 mile scale, and the complete network of local roads do not appear unless the 1/4 or 1/8 mile scale is selected.

The Etak navigator also displays other helpful navigation information. One of the most useful pieces of information is the "destination star" which is displayed on the exact location that is programmed by the user. Single streets, intersections, or street addresses can be used as destinations. In addition to the destination star, an arrow pointing toward the destination (from the current location) is always displayed, as is an arrow pointing

North. The arrow pointing to the destination can be an extremely helpful navigation aid since the destination star is not always displayed (i.e., when the distance to the destination is greater than the currently displayed area). The navigator display is shown in Figure 1.

It must be remembered that the same human factors issues that are considered in the analysis of any novel display/control system must be considered with respect to the navigation display. This type of device represents completely new technology; information of this type has never before been presented with a dashboard instrument. Further, it is believed that no scientific studies have yet set out to empirically and objectively evaluate the efficiency and effectiveness of such a display. Therefore one goal of the present research effort was to evaluate the efficiency and effectiveness of a moving-map display compared to conventional methods of navigation.

Figure 1. Navigator CRT display and driver's view of hood mounted camera.

COGNITIVE MAPPING AND NAVIGATION

The act of navigation has existed in some form for as long as the human race itself. Any means of locomotion requires one to navigate along a familiar or unfamiliar path. Seagoing navigators aided by sextants used the stars to guide their vessels centuries ago. Maps and charts of all sorts have also been used for centuries by travellers in unfamiliar environments.

The concept of navigation can be applied to situations other than when one is directing a vehicle or oneself through physical space. For example, one must navigate through the different levels and branches of a hierarchical computer file. Many experienced computer users could testify to the usefulness of a map or structural flowchart to prevent becoming "lost" within the file structure, illustrating the navigational nature of the task.

To extrapolate further, it can be argued that one can mentally navigate through an internal representation of a given space. An example of a represented space may be the imagining of a familiar route such as from one's home to the grocery store, or it may be an understanding of the underlying structure of the aforementioned computer file. Such internal spatial representations are referred to as cognitive maps. A formal definition of the process of cognitive mapping is: "Cognitive mapping is a process composed of a series of psychological transformations by which an individual acquires, codes, stores, recalls, and decodes information about the relative locations and attributes of phenomena in his everyday spatial environment" (Downs and Stea, 1973, p. 9).

An example of a well structured, useful cognitive map is the system by which Puluwatan Islanders navigate among the neighboring islands in their sector of the Pacific Ocean (Neisser, 1976). The Puluwatan Navigators take subtle cues from the ocean environment and relate them to the cognitive map of the islands; they refer to this system as etak. Note that this is where the Etak Navigator got its name. The islanders' system of navigation makes use of known relationships among stars and the neighboring islands, but these key reference points are often totally obscured. It is with the cognitive map of the underlying structure of the islands and stars that the Puluwatans organize the subtle directional and location cues into a viable navigation system.

Cognitive maps have been referred to as orienting schemata by Neisser (1976); the etak system exemplifies this construct. The cognitive map is a scheme or system within which data can be organized, interpreted, and used in a feedback loop to restructure the cognitive map.

Clearly, navigation within a familiar environment involves the use of and presupposes the existence of cognitive maps. The words <u>familiar environment</u> imply this directly. Even if one views travelling along a familiar route as nothing more than a chain of stimulus-response paired associations, the fact that one can mentally "view" the traversing of a familiar route shows that some internal representation exists, and this can be considered a cognitive map (Downs and Stea, 1973). Simply put, cognitive maps are one theoretical approach to understanding the human's ability to store and organize spatial information.

Review of Navigation/Map Literature

Much work has been done on the psychological aspects of the approach, perception, and learning of maps. However, little work has been done on the process and strategy of the act of navigation. For example, it is the thesis of Evans (1978) that attitudes toward maps filter perception of the information contained therein. Accordingly, differential attitudes toward one or another method of navigation could affect perception of the underlying structure of the area, and thus navigation strategy and efficiency.

Knowledge gained from navigation compared to that gained from map study has been evaluated. Thorndyke and Hayes-Roth (1980) conducted a study in which subjects were evaluated on an orientation task. Their results showed that navigation-trained subjects performed better than map-trained subjects. In a similar line of research, Carr and Schissler (1969) were concerned with navigation as a means of developing or contributing to a cognitive map. Eye movements of drivers and passengers were recorded and related to the individual's representation of the traveled route. They concluded that what is available in the visual environment, to a large extent, determines what is fixated upon for most subjects, and that the effects of individual differences are minimized.

Wetherell (1979) compared navigation performance of subjects who learned a route with verbal instructions to the performance of those who learned the route by studying a map. The verbal instructions subjects were able to navigate the route, but the map study subjects were not. This result could have been anticipated for two reasons. First, the subjects trained with verbal instructions were presented with explicit information on how to navigate the route, whereas the map study subjects had to determine implicit route information from a map. Second, it is believed that memorizing a brief set of verbal instructions would be a simpler task than interacting with the complex visual image that is a map.

A study by Streeter, Vitello, and Wonsiewicz (1985) produced similar results. They compared customized paper maps to taped verbal instructions as means of navigating in an automobile. In addition, one group of subjects was given both methods to use, and a fourth group served as a control; they were provided with a standard paper map of the general area which did not show all streets. The group using taped verbal instructions produced the shortest routes to the destination (time and distance), and they produced the fewest errors. Based on these results, the authors recommended that guidance aids be presented verbally. This solution would still require that all relevant information about a given area be stored, and that algorithms or rules be developed that would integrate the stored information into a useful set of verbal instructions for any given starting point and destination.

Spatial Ability

An issue that has been addressed in the map/navigation literature is the effect of individual differences. Individual differences are relatively unchanging facets of personality which indicate general abilities and styles of cognitive behavior of individuals (Goldstein and Blackman, 1978; Neisser, 1976; Scott, Osgood, and Peterson, 1979; Witkin, 1978). One dimension along which individuals can be differentiated is that of spatial ability. This construct can be broken into identifiable facets: (1) imagining an object from multiple observer perspectives, (2) rotations and transformations of mental images (spatial relations), and (3) complex folding and distortion of mental images (Carter and Wolstad, 1985). In general, the construct of spatial ability can be seen as the ability to store, organize, and recall information pertaining to shapes and fields and the relationships among items within those fields.

Researchers at Rand Corp. have conducted a series of studies on map learning behavior; included in these has been the issue of the effect of spatial ability on strategy and skill in map learning. Stasz and Thorndyke (1980) found that subjects with high visual-spatial abilities demonstrated better overall learning performance than those with low visual-spatial abilities. They further determined that although subject-selected strategies contributed to performance outcomes, individual differences in spatial ability were more prominent. The logical question as to the effect of individual differences on strategy selection was addressed by Stasz (1980). She found that effective attention focusing strategies were used by 80% of the high ability subjects, whereas half of the low ability subjects used no identifiable strategy at all. The effectiveness of the strategies was validated by the fact that those who used the effective strategies performed better than those who did not, regardless of ability.

Measures of spatial ability

Classification of subjects along any psychological dimension is only as meaningful as the validity and reliability of the classification instrument. Therefore if one assumes that the construct of interest exists and is of importance in determining the strategy and outcome of tasks which tap into that construct, then questions of strict construct validity and reliability across time become critical.

Various measures of spatial ability have been developed. For example, Stasz and Thorndyke (1980) used the Group Embedded Figures Test (GEFT) to determine spatial ability. The test involves locating a simple figure in a complex pattern. This test was originally developed to measure the specific construct of Field Dependence/Independence, which is a cognitive style related to spatial ability (Oltman, Raskin, and Witkin, 1971). The Manikin Test is a test of spatial ability developed by Benson and Gedye (1963). This test involves viewing a two-dimensional manikin that is oriented in various ways. The subject's task is to identify in which hand, right or left, the target object is held by the manikin. It has been shown that this measure (if scored properly) is reliable for initial as well as repeated measures (Carter and Wolstad, 1985).

One useful source of cognitive tests is the Manual for Kit of Factor-Referenced Tests (Ekstrom, French, Harmon, and Dermon, 1976). This kit provides tests whose reliability and validity have been cross verified in the measurement of specific constructs. Carter and Wolstad (1985, p. 211) used some of these marker tests to identify the specific construct or factor being tapped by the Manikin Test. They claim that these marker tests identify "known dimensions of mental ability along which people differ." Three constructs from among the 23 referenced in the kit are closely related to navigation behavior.

Perceptual speed is a factor which measures "speed in comparing figures or symbols, scanning to find figures or symbols, or carrying out other very simple tasks involving visual perception." (Ekstrom, et al., 1976, p. 123). The visual search nature of navigation (from the environment as well as from a map or map display), and the fact that efficiency and effectiveness are largely dependent upon the speed with which one perceives the relevant cues in each scenario, points to the importance of this factor in determining performance levels of individuals in navigational tasks.

One of the three tests provided to measure this factor has face validity with regard to navigation and map perusal; it is the Identical Pictures Test (Ekstrom, et al., 1976, p. 124) in which "the subject is to check which one of five numbered geometrical figures or pictures is identical to the given figure at the left end of the row." This test is administered in two parts, each of 90 seconds duration.

Another referenced construct with direct relevance to navigation is spatial orientation which is defined as "the ability to perceive spatial patterns or to maintain orientation with respect to objects in space" (Ekstrom, et al., 1976, p.149). The key aspect of this construct that makes it relevant is the fact that bodily orientation of the observer is an essential part of the problem.

The ability to orient and reorient ones body may become crucial in the use of paper maps in that the user is required to continually physically adjust and rotate the map, or mentally reorient him or herself as the vehicle changes direction. This is an important issue in the comparison of paper maps to navigational displays, because with a navigational display, location and heading information are explicitly provided at all times. Therefore the ability to orient oneself in space may determine the degree of success that one has in using a paper map, but it may have less to do with success in using a navigational display.

The Cube Comparison Test (Ekstrom, et al., 1976) measures spatial orientation in a fashion most relevant to navigation. This test is composed of two parts, each with 21 items. Each item presents two drawings of a cube with six unique faces. Assuming no cube can have two faces alike, the subject's task is to determine if it is possible for the two cubes to be the same. This test is administered in two parts lasting three minutes each.

The third construct of relevance is that of spatial scanning which is defined as "speed in exploring visually a wide or complicated spatial field" (Ekstrom, et al., 1976, p. 155). This construct relates to navigation and map perception directly, since a map, map display, or actual environment are all complicated spatial fields which require visual exploration.

The Map Planning Test, a measure of the spatial scanning construct, has a great deal of face validity with regard to navigation and map perception. The subject is presented with diagrams which represent simplified city maps including buildings and blocked streets. The task for the subject is to find the shortest distance between two specified points without traversing blocked paths. This test is administered in two parts, each of three minutes duration.

Automobile Navigation

Automobile navigation is a special kind of navigation with a number of factors contributing to its uniqueness. Unlike navigation across a desert or sea, the choosing of a route must coincide with the existence of streets, roads, and highways. These roads have names and route numbers, and they are usually explicitly labeled with street signs. Along these roads are parks, buildings, and other landmarks that could be used to identify location and determine direction.

But even with such cues drivers tend to get lost or spend a great deal of time searching for destinations in unfamiliar environments. This makes sense with regard to the concept of the cognitive map; without the orienting schema of the cognitive map (i.e., travelling in an unfamiliar area) stimulus cues such as landmarks or street signs tend to be less meaningful.

To conserve search time and avoid becoming lost, drivers have traditionally used maps to navigate. Paper maps perform a similar function to cognitive maps, or perhaps a paper map can be viewed as an aid in developing a cognitive map. In either case, the paper map helps to provide an orienting schema within which information can be organized. For example, without a map the crossing of a certain street in an unfamiliar area may have no meaning to a person searching for a specific street. However, with a map one could determine that the crossed street is two blocks before the target street. In this way the information has been organized and used for navigation as opposed to simply being monitored and discarded.

The same principle applies to the use of the moving-map navigational display. However, there are key differences between maps and navigational displays. A navigational display presents the map information in a constant and convenient location which is always available to the driver. It requires no holding, folding, or unfolding as does a paper map. In addition it presents information more efficiently than a map, since the specific location and orientation of the vehicle on the map is always shown.

All of these together may result in the moving-map display producing improved navigation performance and being less troublesome to use than a paper map. There is research to support the notion that a map display will produce better performance than a paper map. Collins, Adams, and Pew (1978) compared a computer-assisted map tutorial system with a graphic display to the same tutorial system using a paper map. The system dynamically updated the graphic display based upon the context of the learner/computer interaction; such things as level of detail and the presentation of labels were varied. This dynamic system is analagous to the manner in which a dashboard navigational display presents information to the driver. Results showed that the learning of location information was significantly improved with the dynamic, graphic display over the paper map. It appears that the dynamic map display focused learners attention on the relevant aspects of the map. Although this was, again, a map learning study and not a navigation study per se, the results are significant with regard to the salient issues of computer generated, dynamically updated map displays and their possible superiority to conventional, paper maps in terms of format of information presentation.

ADDITIONAL FACTORS INFLUENCING NAVIGATION

Age

Age is expected to play a significant role in the performance of navigational tasks. Monty et al., (1985) found an older group of subjects (ages 45-70) performed worse than a younger group of subjects (18-30) on many parameters of driving performance. Task times were longer for older subjects; such tasks included tuning the radio, adjusting the climate control, etc. Also, older subjects required a greater number of glances to the display per task.

Monty et al., (1985) noted that part of the problem for the older group of subjects was visual limitations; they seemed to have difficulty in focusing at an appropriate distance to read the CRT/TED labels and focusing at a distance appropriate for driving. Another problem for the older group was one of a lack of familiarity with modern, computer technology.

Rackoff (1975) performed a study specifically to compare older (60s) subjects to a younger group (20s) with regard to inherent abilities and driver visual search patterns. Using gaze dispersion and voluntary visual occlusion as a means of deducing perceptual speed, Rackoff concluded that older subjects required a greater number of cues, and required longer periods of time to perceive and process those cues. The fact that differential risk taking behavior may have influenced the results was not considered. Other studies have shown similar decrements due to age (see Rackoff, 1975).

In addition to the other decrements due to age, Evans (1980) has noted that there are age related decrements in spatial ability as well. This would theoretically affect the navigation task and the tests of spatial ability.

Driving Experience

A study by Cohen and Studach (1977) has shown a relationship between driving experience and driver gaze patterns. Subjects who drove more than 20,000 km/yr were considered experienced drivers, and those who drove less were considered inexperienced. It was determined that differences between the two groups depended upon whether the road was curved to the left or right; differences that did occur showed experienced drivers to have shorter glance times than inexperienced drivers. It is possible that this may have been the result of the experienced group having more well developed scanning strategies (i.e., they were less dependent on any one glance for information, and more on the overall picture derived from a complete scan).

Gender

Gender was not expected to play a major role in differentiating subjects' navigation performance; few consistent gender differences have been shown to exist with regard to driving performance when critical factors such as driving experience and time on the road are controlled (Carr and Schissler, 1969). However, Monty et al. (1985) did find that females looked to the control/display panel more times than males in the performance of simple tasks.

Also, surveys concerning gender and spatial ability have concluded that no systematic trends could be attributed to gender when confounding factors such as extent of exposure are controlled (Evans, 1980; Sherman, 1978).

Environmental Factors

Traffic density

It was previously indicated that monitoring traffic is a secondary driving task; it could equally be considered on a continuum between a primary and a secondary task. The monitoring of traffic in a densely congested area demands much more attention than a sparsely populated street. Rockwell (1972) noted that headway, which is measured as the time taken to reach a point just crossed by a leading vehicle, increases with traffic density; this indicates that drivers are compensating for the heavy traffic by putting more of a time buffer between themselves and the traffic. Because of the effect traffic density has on diverting attention and driver strategy, it was felt that this factor should be controlled in any on-the-road driving experiment to reduce unaccounted variance.

Road type

Research has shown that road type may play a role in driver performance. Monty et al. (1985) showed that in lane keeping and other measures, two-lane state highways produced poorer driving performance than four lane divided highways, and city streets. Zwahlen (1981) noted that a disproportionate number of accidents occur on two-lane highways, and that these roads are often in substandard conditions. Because of these problems and the differences in the cues presented by each type of roadway, it was felt that this factor should also be controlled to reduce unaccounted variance.

EYE MOVEMENT RESEARCH

Although not much research exists on the process and strategy of automotive navigation, there is a well documented research paradigm that should prove useful in this endeavor. Eye movement data have been gathered for decades to determine to which features of the visual field subjects are attending, for what duration, and with what frequency (Carr and Schissler, 1969). These data are not too difficult to gather and interpret because of the way in which humans scan the field of view. A series of glances on specific focal points (corresponding to the foveal region of the retina) are interspersed with saccadic eye movements or transitions to new glance points. Virtually no visual perception occurs during these transitions, so visual input is in a sense made up of a rapid series of still images (Carr and Schissler, 1969). Because of the discrete, serial nature of visual glance, the researcher can, with an accurate eye position measuring device, determine the order, frequency, and duration of glances.

The specific location of a glance is very important in any analysis of eye movement data, because it has been asserted that active cognitive processing can only occur on input from an outer limit of two to six degrees of visual angle around the point of glance, and that effective peripheral vision (which it is believed guides glance selection) extends to about 20 degrees (Carr and Schissler, 1969).

Eye movement research has been conducted in the automotive environment for many years. In many areas of automotive research it has been considered of prime importance since, clearly, the visual sense is the most important in the driving environment. Taste and smell play virtually no role at all. Hearing is of minimal importance; though sirens, horns, tire screeches, and turn indicator blinks all contain auditory information which can be helpful or even life saving in isolated instances. The second most important group of senses are the tactile, proprioceptive, and kinesthetic senses. These help to provide the driver with a sense of speed and movement (i.e. vibrations), acceleration in all six directions (up, down, left, right, backward, and forward), and current position of the steering wheel and pedals.

Still, as was stated above, the main part of the primary driving task is compensatory or pursuit tracking, and speed maintenance; visual input is almost solely responsible for providing feedback in the performance of these two tasks. Having established the largely visual nature of driver information monitoring, the question arises as to what the driver sees. Mourant and Rockwell (1970) described the visual aspect of the driving task as sampling from a continuous stream of information; sources of this information include the front windshield, all side and rear windows, all side and rearview mirrors, and the instrument cluster.

Cohen (1981) has gleaned from the literature that there is a close correspondence between seeing and thinking, and that the pattern of eye movements directly indicates the cognitive processes directing these eye movements. Cohen used a NAC eye mark recorder to measure the duration of subjects' eye glances on slides in the laboratory and on actual roadway scenes. He found that glances were of greater duration while viewing slides in the laboratory. This could be explained by the fact that subjects were worried about maintaining control of a vehicle on the road, whereas there were no such considerations in the laboratory. In support of this, it has been found that, under stress, when tasks in the driving environment were performed with a complex display, glance duration did not change, rather the number of glances per task was increased. This allowed the driver to continually sample visual information regarding the roadway and traffic, while time-sharing the instructed experimental tasks (Monty et al., 1985). Mourant and Rockwell (1970) compared the gaze characteristics of drivers in a controlled, car following paradigm to those of drivers in a regular, uncontrolled driving situation. They showed that number of glances increases as complexity of the driving scenario increases.

Mourant and Rockwell (1970) also found that as familiarity with a given area increased, there was a corresponding narrowing of the gaze pattern. A measure of this kind would allow for the comparison of the familiarity with a route brought about by use of a particular navigation method.

It has also been found that the number of direct looks per unit time to a control/display panel increased with hand travel distance to the control (Mourant, Herman, and Moussa-Hamouda, 1980). This seemingly simple finding could lead to the conclusion that a moving-map display may be superior to a paper map simply because of the greater ease of manipulation in general.

Once eye data are gathered, the glance and joint probabilities between glance locations can be generated using link analysis (Wierwille, 1981). A single link is defined as the relationship between two items in a system, and link analysis is typically a technique used for optimizing design layouts based on the strength of the links. The arrangement of such things as humans and machines in a control room or instruments on a panel can be optimized using link analysis.

Optimization criteria can include expert assessment of the importance or expected frequency of use of the items or links between items in a system. If two instruments are expected to be regularly viewed in succession, then the link between them can be said to be a strong one based on the frequency criterion. If the information presented by two instruments in tandem is considered critical to system operation, then that link may be said to be strong based on the criterion of importance (Thomson, 1972).

In addition to expert analysis, data can be gathered on existing systems or system mockups to empirically determine the strength of the system links based on the criterion of frequency (Wierwille, 1981). Gathering such data yields link value probabilities (defined to be proportional to the sum of the joint probabilities); a strong link would have relatively large link value and vice versa.

This same procedure can be applied in ways other than layout optimization. For example, drivers visually fixate on various images in the environment such as signs and landmarks, traffic, the roadway, maps or other navigational aids, the instrument cluster, etc. Link values among these can then be computed from the glance data to determine patterns of eye movements and driver visual scanning strategy.

PROBLEM SYNOPSIS

The breadth and manner of information presentation to the driver of the modern automobile has been greatly broadened and, in some cases, fundamentally changed by recent advances in microchip and display technology. Many electromechanical analog instruments have been converted to digital formats and some have been relocated to centrally mounted multifunction displays. Further, new instruments have been developed to fulfill functions heretofore nonexistent in the driving environment (e.g., the trip monitor computer). With the advent of this new technological capacity comes the responsibility to insure that the new instrument cluster is at least as effective and efficient as the standard equipment it replaces.

One of the newest of these instruments is the moving-map navigational display. This instrument presents dynamically updated, graphical map information to the driver. The map display is updated based upon the location of the vehicle in the mapped area, and the specific location of the vehicle on the map is also shown.

The fact that information of this kind has never before been presented to the driver requires that systems of this kind be given close scrutiny with regard to effectiveness and efficiency relative to conventional means of navigation such as travelling along a memorized route or using a paper map.

From a more global view, this study was also concerned with the navigation strategies adopted by drivers and the effects of the different methods of navigation on strategy selection. Since the primary way in which information is gathered while driving is through the visual channel, the pattern of eye movements exhibited by the driver was considered the best indication of the navigation strategy of drivers.

To understand navigation strategy, one must first understand the construct of cognitive mapping. A cognitive map is an internal orienting scheme or system within which data can be organized, interpreted, and used to update the cognitive map. Because spatial information is coded in cognitive maps, for one to navigate through space requires the use of a cognitive map. In this context, paper maps and navigational displays can be thought of as contributors to or aids in developing one's cognitive map of a given space.

There is research to suggest that, because of the spatial nature of navigation, individual differences with regard to spatial ability may determine, to a substantial extent, driver strategy. The influence of spatial ability may be especially pronounced in the context of the different methods of navigation, since a particular method may require more spatial ability on the part of the user.

Research Objectives

The first objective was to evaluate the relative effectiveness and efficiency of three methods of navigation: (1) memorized route, which makes use of a cognitive map only, served as a baseline condition, (2) conventional paper map, and (3) an in-dash, moving-map display (the navigator).

The second objective was to study drivers' navigation strategies and the effect of method of navigation on navigation strategy. With regard to the first two objectives, the factors of age, driving experience, traffic density, and road type were also evaluated.

Furthermore, since navigation and map reading are spatial tasks, an attempt was made to determine the relationships among navigation methods, strategies, and individual differences in spatial ability.

METHOD

Subjects

All subjects were volunteers who agreed to participate in the study for pay at the rate of \$5.00/hr, and every subject was currently and legally licensed to drive in the State of Virginia. In addition to being able to see well enough to be licensed to drive, each subject was further tested with a Bausch and Lomb Orthorater to insure that his or her near and far visual acuity was at least 20/40. (The oldest subject, a 73 year old male, was measured to have 20/50 near and far visual acuity. He was included in the sample, because his vision was felt to be representative of individuals in his age range, and because finding a substitute with his characteristics and better vision would have been extremely difficult.) Subjects reported an average total of 19.83 years driving experience. They reported interacting with computers an average of 10.09 hrs/wk, and they claimed to drive to an unknown destination an average of 2.53 times per month.

Subjects consisted of 32 individuals (eight groups of four). Each group was comprised of subjects taken from each of the following age ranges: (1) 18 to 25, (2) 26 to 34, (3) 35 to 49, and (4) 50 and above. There were twelve males and twelve females, and each gender was represented by six high experience and six low experience drivers. High experience drivers were those who drove 10,000 or more miles per year; low experience drivers were those who drove a total of 2000 to 10,000 miles per year. Individuals who drove less than 2000 miles per year were excluded from the study, because they were considered not to represent those who would use navigational aids on a regular basis. The distribution of subjects among the between-subjects factors is shown in Table 1

Apparatus

Apparatus in the experimental vehicle, a 1985 Cadillac Sedan deVille, included an ETAK Navigator moving-map display, paper maps, a power conversion system, an IBM Personal Computer (PC) with a Metrabyte DASH-8 analog/digital converter card and a Metrabyte PIO-2 parallel port card, a custom-designed computer interface, an accelerator velocity sensor, a steering wheel velocity sensor, a brake actuation sensor, various custom designed push-button panels operating with the interface system, a Setchel-Carlson CCTV monitor, two videocameras and two videorecorders, a video switch allowing the selection of either video camera or the PC video for display on the monitor, and a microphone. Safety features included a passenger-side brake pedal which was available to the front seat experimenter, a citizen's band radio, a fire extinguisher, and a professional first-aid kit. The custom-designed interface and the attached pushbutton panels, the steering wheel velocity sensor, and the accelerator velocity sensor are shown in Figures 2 through 4, respectively.

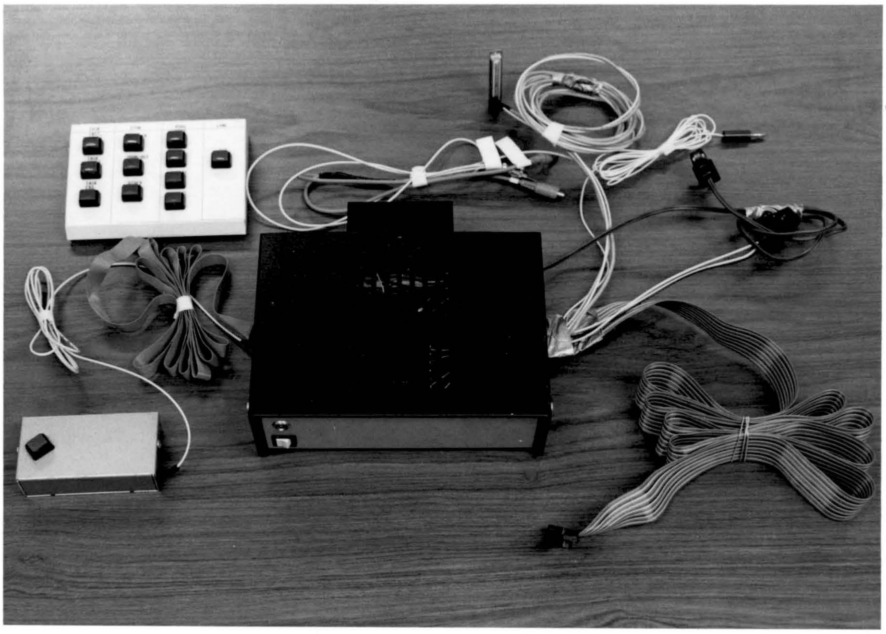


Figure 2. Custom interface and pushbutton panels.

Figure 3. Steering wheel velocity sensor and passenger-side brake pedal.

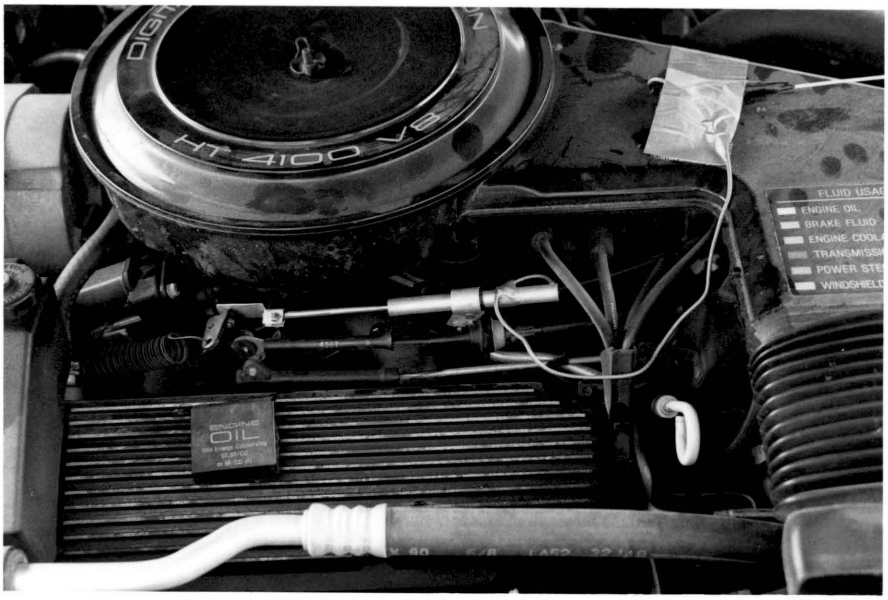


Figure 4. Accelerator velocity sensor (center of picture).

One video camera was mounted on the hood (on the passenger side) and angled to shoot the driver through the windshield. A metal shield was affixed to the windshield to reduce the effects of glare and reflections from the sky. A second camera, fitted with a wide-angle lens, was mounted on the roof, directly over the driver's head and pointing straight ahead. The hood mounted camera provided information on where the subject's eyes were looking, and the roof mounted gave a forward looking view from the point of view of the driver. The camera configuration is shown in Figure 5.

Three routes defined by starting points and unfamiliar destination points in the Blacksburg/Christiansburg/Radford area of Virginia were designated as the navigation routes. Subjects were interviewed to insure that they were unfamiliar with the three destinations. It must be noted that most subjects were familiar with the general area where the research took place, though none knew the location of any of the three specific destinations nor how to navigate to them. Each route was designed to sample three different road types: (1) four-lane divided highway, (2) two-lane, two-way highway, and (3) city street; and each route was designed to match the others in terms of time to complete a route and overall complexity. Each route was physically separate from the other two, there were no common roadways or areas in any of the routes. Appendix C provides more detailed information concerning the experimental routes.

It is possible in the current configuration of the navigator to be guided along an indirect route under certain specific conditions. This can occur whenever a particular scale level indicates that a given heading should be pursued, but the next lower scale level does not show enough area to reveal that the indicated heading is a dead end. This will be referred to as a hidden dead end. The experimental routes were carefully selected to avoid the hidden dead end problem, so that correct use of either the map or the navigator would lead in a direct path from the starting point to the destination.

Figure 5. Dual camera configuration.

Three paper and pencil tests were used to determine individual differences with regard to specific aspects of spatial ability. Perceptual speed was measured with the Identical Pictures Test, spatial orientation was measured with the Cube Comparisons Test, and spatial scanning was measured with the Map Planning Test (Ekstrom et al., 1976).

A questionnaire (Appendix B) was also used to gather demographic information on the subjects, and to insure that their general health and recent activities with regard to sleep, alcohol, medication, and drugs would allow them to safely participate in the study. The last section of the questionnaire was used to gather subject opinions about various facets of the study after participation was concluded.

In addition to the two videorecorders used to gather data in the research vehicle, two separate videorecorders were used in the laboratory for the data reduction process. The use of two sets of videorecorders allowed for the simultaneous reviewing of recent data tapes in the laboratory with the taking of new data in the research vehicle.

Experimental Design

The experimental design was a five factor, mixed-factors design.

Between-subjects factors

Subjects were grouped based upon three factors (1) gender (male and female), (2) driving experience (low and high), and (3) traffic density (low and moderate).

Traffic density was approximated based upon the time of day when the experimental run took place. Runs taking place after morning rush hour until approximately lunch time were considered to be low traffic density runs. Runs taking place during afternoon rush hour were considered to be moderate traffic density runs. Table 1 shows how subjects were distributed as a function of the between-subjects factors.

Within-subject factors

There were two within-subject factors: (1) navigation method, which had three levels: (a) memorized route, (b) paper map, and (c) navigator; and (2) road type, which had four levels: (a) four-lane divided highway, (b) two-lane highway, (c) city street, and (d) stopped. Observations were classified in the stopped category whenever the vehicle was at a standstill; this included when the subject had voluntarily stopped the vehicle to reorient as well as all stops due to traffic signals and signs. The stopped category of road type was included because it was expected that driver scan patterns would be different when actually operating the vehicle compared with the scan patterns exhibited in a stopped vehicle. Since this study is concerned with driving behavior, data gathered while the vehicle was stopped were not analyzed with the rest of the data.

Procedure

All subjects first read an introduction to the navigation study. They then read and signed an informed consent form (Appendix A); this form indicates that they knew and

Table 1

Counterbalancing Scheme for Navigation Method and Route

	Low Driving Experience				High Driving Experience				
	S1	S2	S3	S4	S5	S6	S7	S8	
	$\overline{A1}$	$\overline{C2}$	$\overline{B3}$	$\overline{A1}$	$\overline{A2}$	$\overline{C1}$	$\overline{B3}$	$\overline{A3}$	
Male	B2	A3	C1	C2	C3	B2	A1	B1	
	C3	B1	A2	B3	B1	A3	C2	C2	MODERATE TRAFFIC DENSITY
	S9	S10	S11	S12	S13	S14	S15	S16	
	$\overline{A1}$	$\overline{C2}$	$\overline{B3}$	$\overline{B3}$	$\overline{A2}$	$\overline{C1}$	$\overline{B3}$	$\overline{C2}$	
Female	B2	A3	C1	A1	C3	B2	A1	A3	
	C3	B1	A2	C2	B1	A3	C2	B1	
	S17	S18	S19	S20	S21	S22	S23	S24	
	$\overline{A1}$	$\overline{C2}$	$\overline{B3}$	$\overline{C2}$	$\overline{A2}$	$\overline{C1}$	$\overline{B3}$	$\overline{A1}$	
Male	B2	A3	C1	B3	C3	B2	A1	B2	
	C3	B1	A2	A1	B1	A3	C2	C3	LOW TRAFFIC DENSITY
	S25	S26	S27	S28	S29	S30	S31	S32	
	$\overline{A1}$	$\overline{C2}$	$\overline{B3}$	$\overline{B1}$	$\overline{A2}$	$\overline{C1}$	$\overline{B3}$	$\overline{C2}$	
Female	B2	A3	C1	C2	C3	B2	A1	B3	
	C3	B1	A2	A3	B1	A3	C2	A1	

Navigation Methods: (A) Paper Map, (B) Memorized Route, (C) Navigator
Experimental Routes: (1) Radford, (2) Christiansburg, (3) Blacksburg

understood their rights as participants in the study, and that they knew, and understood the inherent risks that they incurred as participants in the study. Subjects' near and far visual acuity were then checked with the Orthorater. Next, subjects spent approximately 30 minutes taking the paper and pencil tests of spatial ability.

The three methods of navigation that were tested included: (1) memorized route, (2) paper map, and (3) navigator, a moving-map display. In the memorized route condition, subjects were shown a route, in detail, on a map which they could study; they were not allowed to look at the map again in the memorized route condition. Subjects then drove along the full length of the route, then back again along the same route to the starting point. The next run to the destination without a mistake in following the prescribed route was considered the data run. The routes were not trivial to learn, and several subjects took two or three tries before the route could be navigated in an error-free fashion.

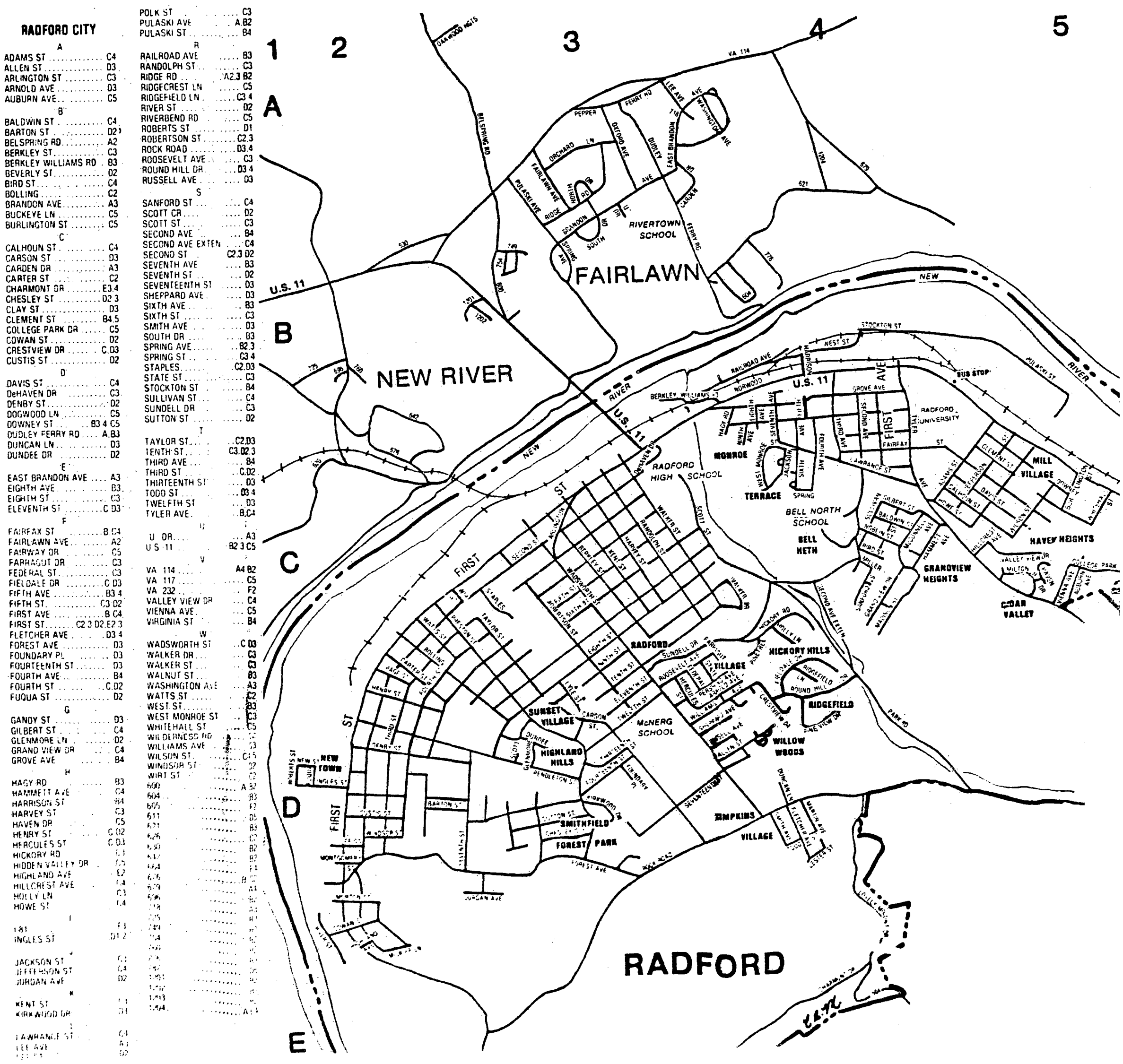
Prior to the study, each subject was thoroughly trained in the use of the navigator. Training began by having each subject read important features and safety warnings adapted from the owner's guide (Etak, 1985b). Detailed training was then given in the experimental vehicle while the vehicle was still parked. The subject was then allowed to practice deriving navigation information from the navigator while driving. The final phase of the training procedure allowed the subjects to freely use the navigator to actually navigate to an unknown destination; reaching this destination was the training criterion that had to be met for the subject to be permitted to participate in the study.

In addition to this training procedure, each subject participated in the related study reported in Dingus, Antin, Hulse, and Wierwille, 1986). The subject's participation in that study provided much more on-the-road practice in the performance of a variety of navigator tasks. However, it should be noted that the study reported in Dingus et al. (1986) study required no actual navigation on the part of the subjects, only the gathering of specific kinds of information from the navigator system.

Subjects were not trained in the use of the paper maps; it was expected that the experience of the general population with maps would be sufficient. The starting point of each route was marked with a green "S" and the destination was marked with a small red arrow which pointed to a specific intersection; these markings as well as the names of the streets making up the destination intersection were explicitly presented to the subject. Subjects were free to write or draw on the map if they desired, but this was not suggested to them. An example of the type of map used appears in Figure 6 (see Appendix C for a description of the maps and routes).

Each subject drove to the starting point of the first route and was instructed to use one of the methods of navigation to drive to an explicitly specified destination, about 10 minutes away. Subjects were also requested to perform one additional task in the course of navigating to the destinations. They were asked to read aloud any street signs or directional signs that they used to navigate; these spoken data were recorded on the videotape associated with the roof-mounted camera. The order of presentation of the methods and routes was counterbalanced using the counterbalancing scheme shown in Table 2.

Subjects were told to drive to the destination as "efficiently as possible." In an effort to allow the subjects to navigate naturally, subjects were allowed to interpret this instruction as they desired. That is, each subject could optimize the route based on time, distance, simplicity, or some other criterion that he or she decided would make the route most efficient. Subjects were also instructed that, if necessary, they could stop at any safe and legal place to reorient themselves or study the paper map or the navigator display. Subjects were not informed if they committed a navigation error (i.e., a wrong or missed turn); instead a data run was considered complete when the destination was reached or when 20 minutes had elapsed and the subject clearly could not reach the destination in another five minutes. Of course in the memorized route condition, a data run was only



(Map shown is 64% of actual size.)

Figure 6. Example of style of paper map used.

Table 2

Experimental Design (Between-Subjects Factors)

Traffic Density

	Moderate		Low	
	Driving Experience		Driving Experience	
	Low	High	Low	High
Male	S 1-4	S 5-8	S 17-20	S 21-24
Female	S 9-12	S 13-16	S 25-28	S 29-32

considered complete when the subject completed an error-free run. If errors were committed during a potential data run in the memorized route condition, then the subject was informed of the mistake and allowed to drive to the destination. The subject then drove back to the starting point to begin another attempt to complete an error-free run. This process was repeated as many times as was necessary to acheive an error-free run for each subject in the memorized route condition.

This scenario was repeated two more times using the other two methods of navigation and the other two routes. Upon completion of the three experimental runs, the subject was driven back to Virginia Tech and asked to fill out the remaining section of the questionnaire. The subject was then debriefed and paid for the time he or she spent in the study.

Experimenter duties

Two experimenters rode in the car at all times, and each had a responsibility in the online gathering of data. One experimenter rode in the front passenger seat; it was the responsibility of this experimenter to operate the pushbutton panel shown in Figure 7.

This included noting when a run began (i.e., experimenter said: ″You may begin.″), when the subject started driving, and when the run was complete. All zooms in and out on the navigator were counted by the experimenter, as were all lane exceedences. A lane exceedence was considered to occur whenever any part of the vehicle was on or outside of the lane boundary. It was also the responsibility of this experimenter to note when the vehicle was entering a different road type. In addition to his data-taking duties, the front seat experimenter also had the responsibility of operating the emergency brake pedal when necessary, Figure 3. Upon completion of a run, the front seat experimenter noted the exact

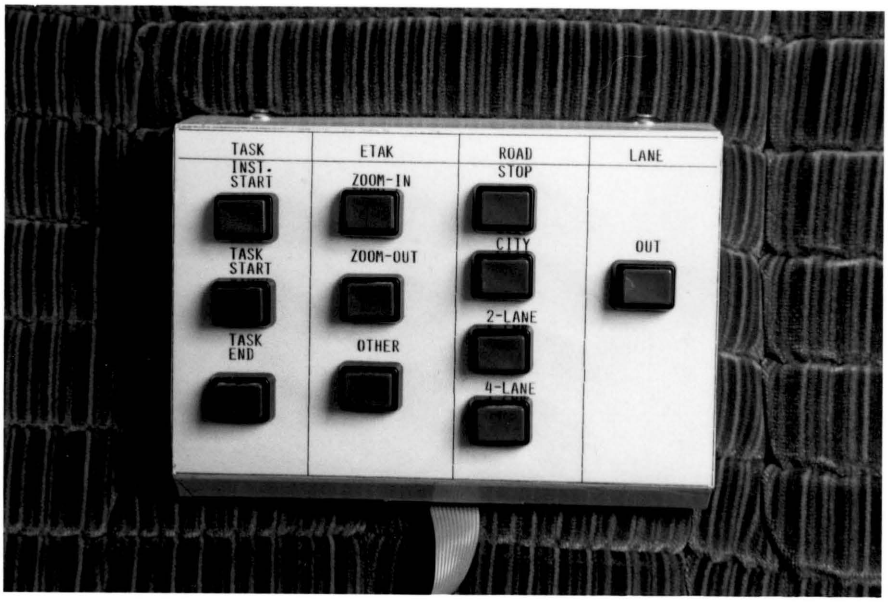


Figure 7. Pushbutton panel used by front seat experimenter.

route driven by the subject on a blank paper map. Although it may seem as if this experimenter was overburdened with these tasks, it should be kept in mind that most of the tasks that he performed occurred with relatively low frequency.

The second experimenter was seated in the back seat in a position to view the video monitor which displayed the hood-mounted camera image (i.e., the subject's face). This experimenter operated a single instantaneous electrical pushbutton. It was depressed when there was a glance (i.e., when eye transition had ceased), and it was released when the glance ended (i.e., when the eyes were in transition). The pressing of this button allowed the determination of the duration of each glance. The distinction between the definition of a glance and a fixation must be made here. A fixation is considered to occur whenever the eyes stop and focus on an image; if there is a change, no matter how slight, there is a new fixation. When a series of fixations are trained on a single object or image, this series of fixations is considered to be a glance. This is not to say that brief fixations were ignored; if the eyes were fixated on one object, then briefly on another, this would be considered two distinct glances. However, if there were several fixations on a single object, then only one glance would be counted. The backseat experimenter's station is pictured in Figure 8.

All measures of driving performance, including the brake, steering, and accelerator sensors and all input from all push-buttons, were first sent to the custom interface system for conditioning and subsequently to the PC for online calculation and storage of the dependent measures on a per glance basis. Data were stored in RAM during a run, and were then transferred onto diskette when the run was completed. This arrangement allowed for a sufficient sampling frequency and for the diskettes to be exposed to minimal vibration, since they were only inserted and used when the car was standing still.

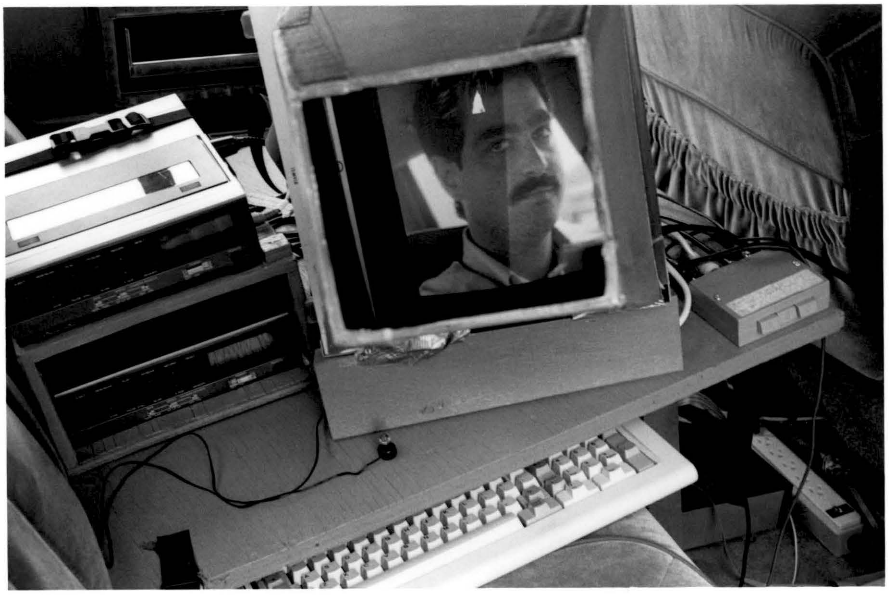


Figure 8. Backseat experimenter station.

Dependent Measures

Time

These data included the time taken to study the map or navigator before beginning to drive to the destination (study time), the time taken to drive to the destination (i.e., from when the car was first put into gear until the destination was reached (drive time), and the sum of the first two (total time).

Navigation effectiveness rating

One key measure of effectiveness of the three methods of navigation is a rating which was assigned to each experimental run based on the directness of the routes selected and the presence of navigation errors. A complete explication of how these ratings were defined and assigned is presented in the Results section of this document.

Eye movement

Recorded eye movement data were brought back to the Vehicle Analysis and Simulation Laboratory for offline reduction, wherein each glance was classified into one of the following glance categories: (1) roadway(center), (2) roadway(offcenter), (3) mirrors, (4) signs and landmarks, (5) map/navigator (depending on condition), (6) instruments, and

(7) other (i.e., for glances not classifiable into any of the other six categories). When the driver's glance was within the forward roadway (observations of the road itself and leading traffic), the driver was said to be looking at the roadway(center). Glances outside the vehicle to the left or right of roadway(center) were classified as roadway(offcenter).

Reviewing the tapes in the laboratory provided information on where the subject was looking within the car. This was accomplished by noting where the eyes were positioned for each glance. The system also provided information on where the subject was looking outside the vehicle. The videotape of the forward roadway was used to help in the classification of the glances outside the vehicle. The data reductionist could see both videotapes, side-by-side during playback. If the subject was seen to look out the windshield to the left, the data reductionist could look at the forward-looking videotape to more accurately determine what the subject was watching. The data reductionist could also listen to the recording of the subject's voice on the forward looking videotape to aid in the detection of glances to signs or landmarks which the subject was instructed to read aloud.

These data provided information on the link values associated with the seven defined glance possibilities, and glance probabilities by category. These data were the main measures of navigation strategy.

The fact that the two recorders remained synchronized in the car during recording (and in the laboratory during playback) made the concurrent use of two sets of tapes feasible. Also, one remote control device could operate both of the playback recorders in the laboratory simultaneously, allowing the two tapes to remain synchronized during pause and rewind functions. In this way, the data reductionist could review any portion of the tape to insure correct glance categorization. The videotape data reduction station is pictured in Figure 9.

The timing of each glance was calculated by the PC online, in the car by the duration that the glance button was depressed. This button also reset the calculations for

Figure 9. Videotape data reduction station.

all of the dependent measures taken, so that each of these was initially calculated and stored on a per glance basis.

Each press of this glance button also recorded a tone on the same videotape with the eye movement data. Each tone was of a higher pitch than the preceding tone, for fifteen glances; on the sixteenth glance the tone pitch was reset to its original level. This cyclic process of successively increasing tone pitch, then resetting it, was repeated throughout the duration of each run. An electronic counter (contained in the custom interface) which reset the tone every sixteen glances also sent a logic high signal to the computer; this was stored with the computer data associated with that particular glance. This allowed the precise synchronization of the computer data with the videotape data. In the laboratory, each low tone (which the data reductionist could hear when reviewing the tapes) could be associated with the correct line of data, since that line of data would be similarly marked with the logic high signal. In this way, there was a low tone once every sixteen glances on the tape, and an associated logic high once every sixteen lines of computer data.

Insuring that these two sets of data were precisely coordinated was critical to the data analysis. The reason for this can be seen in the following example. A long glance to the roadway is stored in the computer as merely a long glance; if the data were not precisely synchronized, then this line of data may be incorrectly categorized as a glance to the navigator giving erroneous and dangerously misleading results. To extrapolate, if this happened on a regular basis, then the all of the glance data would become meaningless.

One measure of relative efficiency is the degree to which use of a navigation method causes the driver to look away from the primary driving task. Therefore the proportion of time spent glancing upon things not directly concerned with the driving task was used as one measure of the relative efficiency of the various methods. Another measure was the percent time spent glancing at the paper map and the navigator in those respective conditions.

Driving quality

Degree of intrusion is also an indicant of the relative efficiency of various methods of navigation. Intrusion can be defined as the change in the performance of the driving task due to the use of a particular method of navigation. Accelerator, brake, and steering measures along with lane exceedences were used to indicate the relative intrusion of each method of navigation on driving performance.

Questionnaire

This was a means of gathering subjects' impressions and preferences regarding the various aspects of the experiment. Also, this information lends insight to the interpretation of the performance-oriented data that was collected.

HYPOTHESES

Navigation Strategy

Although the current literature would not support specific hypotheses of navigation behavior, one possibility regarding the eye movement data was put forth. It was expected that use of the paper map would cause subjects to glance away from the primary driving task a greater percentage of the time than while using the moving-map display.

Effectiveness and Intrusion

The memorized route condition served as a baseline condition, and it was hypothesized that this condition would produce the minimum total time scores and the best driving performance. It was also hypothesized that a moving-map display would prove more effective and less intrusive than a conventional paper map.

Age

Differences among the age groups were expected in terms of navigation performance and the degree of intrusion of the navigation methods on driving performance. It was hypothesized that the younger group would demonstrate more effective navigation behavior, and less intrusion in driving performance.

However, the main effect of interest with regard to age is the differential effectiveness of the navigation methods across age groups. That is, even though the moving-map display may have proven superior to the paper map for the younger group of subjects, this effect may have been marginal or even reversed for the older group. This could be expected due to the slowed information processing capability associated with the aging process, as well as the relative lack of experience with modern, computer-oriented displays on the part of most older drivers.

Gender

It was hypothesized that since driving experience was controlled, no differences due to gender would appear in the data.

Environmental Factors

Traffic density

It was expected that greater benefits of the moving-map display would be attained in the higher traffic density condition.

Road type

It was hypothesized that driving performance would be more greatly intruded upon on two-lane highways than on other road types.

Since each route would sample various road types, there could be no definitive determination of the relative effectiveness of the three navigation methods on the different road types.

RESULTS

The analysis was conducted in several parts. A preliminary set of analyses was performed in an effort to rigorously examine the effects of the confounding nuisance factors in the experiment and to suggest means of controlling these spurious influences.

Analyses were then performed in an effort to evaluate the effect of the independent factors on the dependent measures of interest. The first set of these analyses focused on time measures which were gathered along with the navigation effectiveness rating, to determine the effectiveness of the three navigation methods.

The next set of analyses employed the glance and link value data to evaluate the efficiency of the three navigation methods. Efficiency was also addressed from the standpoint of intrusion; an analysis was performed to assess the changes that occurred in various driving quality measures as a function of navigation method.

The subject factors of age and spatial ability were examined on a post hoc basis in a separate set of analyses. Age was analyzed post hoc so that there would not be only one subject per cell of the design, and spatial ability was analyzed post hoc, because subjects were assigned to spatial ability groups in post hoc fashion without regard to the other factors. Finally the questionnaire data were examined to compare subjects' opinions concerning the various navigation methods to the objective measures of performance.

The Statistical Analysis System (SAS) computer package was employed for all of the analyses in this study. SAS provides three explicit F or F -like test statistics for each factor included in a MANOVA procedure (SAS, 1985). Wilk's criterion provides an exact F statistic, is based on the assumption of normality, and maximizes the power of tests on variables that are normally distributed. The three explicit tests that SAS provides usually form a consensus (the other two F approximations are are Pillai's Trace and the Hotelling-Lawley trace). Since there were no significant differences among the three for any of the analyses performed, only the F based on Wilk's criterion will be reported. An alpha level of 0.05 was used throughout this report unless otherwise stated.

Preliminary Analysis

Preliminary analyses were conducted to determine the effects of the nuisance factors of route, order, and the order-by-method interaction. A multivariate analysis of variance (MANOVA) procedure was performed on various time parameters to this end. The time parameters included (1) study time which was the time taken to study the map or navigator display before putting the transmission in drive, (2) drive time which was the time from when the transmission was put into drive until the destination was reached, (3) total time which was the sum of study time and drive time, and (4) average glance time which was the average time spent on a single glance, regardless of where the glance was directed. Using the residual mean square (MS) as the error term, the MANOVA showed that the nuisance factors of route and order did have an effect on the time parameters, taken as a whole, in the study (alpha = 0.25). Only effects which could have their sums of squares correctly computed were included in the model. All remaining sources of variance were pooled in the residual term. A summary of the results is shown in Table 3.

The sources of variation shown in Table 3 represent the maximum number of factors that could be included in the MANOVA while having their sums of squares correctly estimated. It should be noted that when nonsignificant results are desired, increasing the power of a test by testing at a higher alpha level (e.g., alpha = 0.25) is a conservative measure.

An analysis of variance (ANOVA) was performed on each of the dependent variables used in the MANOVAs to see which, if any, nuisance factors were significant based on the dependent measures taken separately. These analyses were made still more conservative by the removal of the method-by-order interaction from the model. This interaction was not significant in the MANOVA, and its removal resulted in the reduction of the error mean squares. Again, any procedure resulting in the reduction of the error mean square is a conservative procedure if one is trying to show that an effect is not significant. The significant results of the ANOVAs are shown in Table 4.

Three variables did show significant route effects: study time, drive time, and total time. Because of this and the unavoidable differences in the experimental routes, these time parameters were standardized for each route. Standardization was accomplished using the following calculation.

$$(Xij - Xj)/S.D.j = Xij\ (std);\ j = \{1,2,3\}$$

where:

Xij is the ith observation of variable X on the jth route,

Table 3

Preliminary MANOVA on Nuisance Factors

Source	df	*F*	*p*
Route (R)	2	2.76	0.0349
Order (O)	2	3.07	0.0229
M x O	4	1.23	0.3037
Cell (C)†	7		
Navigation Method (M)	2		
R x C	14	0.96	0.5599
M x C	14		
O x C	14		
Sub/C	24		
Error	12		
Total	95		

† Cell represents to which of the eight cells a subject was assigned based on gender, driving experience, and traffic density

Table 4

Preliminary ANOVAs on Nuisance Factors (Significant Effects Only)*

Source	df	STUDY TIME p	DRIVE TIME p	TOTAL TIME p	AVERAGE GLANCE TIME p
Route (R)	2	.0094	.0001	.0001	.0101
Order (O)	2		.2174		.1876
Cells (C)	7				
Nav. Method (M)	2				
R x C	14				
M x C	14				
M x R	4				
Sub/C	24				
Error	26				
Total	95				

* $\alpha = 0.25$

Note that based on the results from the preliminary MANOVA, the navigation method-by-order interaction was removed from the model.

Xj is the mean value of variable X on the jth route,

S.D.j is the standard deviation of variable X on the jth route, and

Xij (std) is the ith observation of variable X standardized by route j.

This eliminates location differences in these parameters due to route, since all means become zero for each parameter on each route.

Prior to standardization, two variables, drive time and total time, were altered to more accurately reflect a subject's performance when he or she failed to navigate to the specified destination. In these cases, a run was terminated when approximately 20 minutes had elapsed and there was no possibility that the subject would reach the destination in the next five minutes. However, some subjects who did reach the destination took longer than 20 minutes. These runs were not terminated in precisely 20 minutes, because the subject appeared to be making reasonable progress toward the destination.

Therefore, instead of recording a shorter total time on a run where the subject was lost than on a run where the subject successfully navigated to the destination, the following change was implemented. Each total time on a run where the destination was not reached was assigned the value just greater than the maximum total time for any run where the destination was reached in any condition. Since the maximum total time taken in any condition to reach the destination was 23.34 min, 24.0 min was the total time assigned to all runs where the destination was not reached. It was felt that this was a conservative procedure, since these runs, if allowed to continue, would certainly have lasted longer than 24.0 min. Yet this procedure also insured that no run where the destination was reached would produce a total time score longer than a run where the destination was not reached.

Although several variables showed an order effect (alpha = 0.25) no additional scheme was implemented to control for this effect, since the counterbalancing scheme employed (See Table 2) should distribute this effect relatively evenly across the main factor, navigation method. A key finding of the preliminary analysis is that there was no method-by-order interaction. If there had been, this would have indicated that order of presentation of the navigation methods differentially affected the dependent measures, and would have made estimation of the true method effects difficult.

Effectiveness Analysis

A MANOVA was performed to determine the effectiveness of the three navigation methods as well as the effects of the blocking variables: gender, driving experience, and traffic density. The MANOVA revealed only navigation method to be significant results are summarized in Table 5.

An ANOVA was also conducted on each of the variables included in the MANOVA. Only navigation method was significant for any of the dependent measures. The measures for which method was significant were: study time, drive time, total time, average time per glance, average time per glance to a sign or landmark, and average time per glance to the roadway(center). Post hoc comparisons on these variables showed that the paper map produced study times which were significantly greater than the navigator which were significantly greater than those produced by the memorized route condition. The memorized route condition produced drive times and total times that were significantly shorter than those produced by the other two conditions. Average time per glance and average time per glance to a sign or landmark were significantly shorter in the navigator condition compared to the other two conditions. The memorized route produced an average time per glance to the roadway(center) which was significantly greater than that

Table 5

MANOVA on Time Parameters

Source	df	*F*	*p*
Between-Subjects			
TRAFFIC (T)	1	0.42	0.9077
EXPERIENCE (E)	1	0.69	0.7110
GENDER (G)	1	1.01	0.4710
T x E	1	0.68	0.7200
T x G	1	0.39	0.9225
E x G	1	0.80	0.6190
T x E x G	1	0.91	0.5369
SUB(T x E x G)	24		
Within-Subject			
METHOD (M)	2	25.15	0.0001
T x M	2	1.72	0.0520
E x M	2	1.03	0.4352
G x M	2	1.13	0.3407
T x E x M	2	1.64	0.0702
T x G x M	2	0.82	0.6684
E x G x M	2	1.13	0.3405
T x E x G x M	2	0.90	0.5859
M x SUB(T x E x G)	48		
TOTAL	95		

produced by the paper map which was significantly greater than that produced by the navigator. These results are summarized in Table 6.

A separate ANOVA was performed on the variable representing average time during a run that a subject spent per glance looking at either the paper map or the navigator, average time/glance-map/navigator. This variable was not included in the MANOVA, because it may have unfairly affected the results (i.e., average time/glance-map/navigator would be close to zero and would have no real meaning for the memorized route condition). Results of the ANOVA showed navigation method to be highly significant with regard to this variable. However, the more relevant post hoc comparison revealed only that the memorized route condition produced significantly lower average time/glance-map/navigator scores than the paper map and navigator conditions, which, of course, was expected. The more interesting result is that there was no difference between the paper map and navigator conditions with regard to this variable. A summary of the results is included in Table 6.

Navigation effectiveness rating

One key measure of the effectiveness of the three methods of navigation is a rating which was assigned to each experimental run based on the directness of the routes selected and the presence of errors. Errors included the passing of a street that was eventually selected, or turning onto the wrong street briefly before making a U-turn back to the correct street. In certain cases, the determination of whether an error was committed or an indirect route was chosen was based on the judgement of the experimenter. Integers (1 - 5) were assigned based on the following criteria:

Table 6

Means and Newman-Keuls Post Hoc Comparisons on Time Measures

Method	Study* Time (min)	Drive* TIME (min)	Total* TIME (min)	Average TIME/ GLANCE (sec)	Average TIME/ GLANCE Sign (sec)	Average TIME/ GLANCE Roadway Center (sec)	Average** TIME/ GLANCE - Map/Nav (sec)
Paper Map	1.55(A)	14.00(A)	15.55(A)	2.69(A)	1.34(A)	4.25(B)	1.52(A)
Mem. Route	0.02(C)	11.02(B)	11.04(B)	3.00(A)	1.30(A)	5.09(A)	0.06(B)
Nav.	0.75(B)	15.20(A)	15.95(A)	1.54(B)	0.80(A)	1.85(C)	1.37(A)

Means with same letter are not significantly different ($\alpha = 0.05$).

*Non-standardized means shown.

**This variable was not included in MANOVA.

1 - The destination was not reached in 20 minutes, and the subject appeared hopelessly lost.

2 - The destination was reached, but an indirect route was selected and errors were committed.

3 - The destination was reached, but an indirect route was selected; no errors were committed.

4 - The destination was reached, and a direct route was selected, but errors were committed.

5 - The destination was reached, a direct route was selected, and no errors were committed.

These data were standardized by route to control for any route differences which may have made one destination more difficult to navigate to than another. Since these ratings provide ordinal data only, a Kruskal-Wallis nonparametric one-way analysis was employed. This provided a Chi Square approximation, $\chi^2 = 38.65$, $p < 0.0001$. However, an inspection of the raw data showed that although the memorized route condition produced navigation effectiveness ratings that were significantly greater than when subjects had to use a paper map or the navigator to navigate, there were few difference between the paper map and the navigator on this variable when in terms of the three measures of central tendency, mean, median, and mode. However, an examination of the distributions of this variable shows that the navigator produced ratings that were more heavily weighted toward either end of the rating scale, whereas the paper map produced ratings which were more heavily weighted toward the center of the rating scale. It is interesting to note that out of the 64 runs where it was possible for a subject to not reach the destination, it only occurred seven times: four times while the subject was using the navigator, three times while the subject was using a paper map. Each occurred on the first of the three experimental runs for that subject. The distribution of ratings, measures of central tendency, and number of incomplete runs are shown in Table 7.

Efficiency Analysis

Glance probability analysis

The relative efficiency of the three navigation methods can be viewed as the degree to which each method causes the driver's gaze to be diverted from the things directly concerned with driving, presumably due to the demands of the navigation method being used. As has been previously stated, each glance was classified into one of seven glance categories: (1) roadway(center), (2) roadway(offcenter), (3) mirrors, (4) signs and landmarks, (5) map/navigator, (6) instruments, and (7) other. From this categorization scheme were calculated the fraction time spent on each of the categories for each run. The fraction of time spent glancing at the three categories: mirrors, instruments, and roadway(center) were summed for each run to create an EYEDRIVE variable. This variable indicates for each run the proportion of time spent glancing upon items directly concerned with driving the vehicle. Glances to the roadway(offcenter) were not included in the EYEDRIVE variable, because it was felt that glances to this category represented the search for navigational cues moreso than driving behavior. An ANOVA on this variable showed navigation method, traffic density, and gender to be significant. The traffic density-by-driving experience interaction was also found to be significant. A summary of the results appears in Table 8.

Table 7

Navigation Effectiveness Ratings and Number of Incomplete Runs

	Memorized Route	Paper Map	Navigator
Navigation Effectiveness Rating Means	5	3.063	3.063
Navigation Effectiveness Rating Medians	5	3	3
Rating Distributions			
1s	0	3	4
2s	0	7	11
3s	0	14	5
4s	0	1	3
5s	32	7	9
Number of Incomplete Runs*	0	3	4

Values are given in raw (unstandardized) form.

Memorized route values, by definition, are constrained to those shown.

* Number given is total out of 32 runs for each method.

Table 8

ANOVA on EYEDRIVE

Source	df	*F*	*p*
Between-Subjects			
TRAFFIC (T)	1	4.43	0.0460
EXPERIENCE (E)	1	1.65	0.2113
GENDER (G)	1	6.49	0.0177
T x E	1	5.31	0.0301
T x G	1	2.43	0.1321
E x G	1	0.01	0.9254
T x E x G	1	0.21	0.6493
SUB/T x E x G	24		
Within-Subject			
METHOD (M)	2	169.10	0.0001
T x M	2	2.87	0.0666
E x M	2	0.48	0.6203
G x M	2	0.33	0.7196
T x E x M	2	1.22	0.3053
T x G x M	2	1.23	0.3000
E x G x M	2	0.46	0.6354
T x E x G x M	2	0.00	0.9993
M x SUB/T x E x G	48		
TOTAL	95		

A post hoc analysis of the means showed that all three navigation methods differed significantly from one another with regard to EYEDRIVE; the order from highest to lowest was: memorized route, paper map, then navigator. This is shown in Table 10.

The moderate traffic density mean was 0.79 compared to the low density mean of 0.76. Males produced an EYEDRIVE mean of 0.75 compared to the female mean of 0.79. The significant traffic density-by-driving experience interaction is depicted graphically in Figure 10.

Another ANOVA was performed on the variable EYEMAP/NAV. This variable represents the proportion of time spent looking at the paper map or navigator during a run. This variable would obviously be near zero for the memorized route condition. It was not always exactly zero, because subjects' glances sometimes briefly strayed to the navigator, even though the display was disabled during the paper map and memorized route conditions. Two main effects, navigation method and traffic density, proved to be significant (Table 9).

The moderate traffic density condition produced a mean EYEMAP/NAV value of 0.12 compared to the low density mean of 0.15. A post hoc comparison showed that the three navigation methods differed significantly; the order from highest to lowest was: navigator, paper map, memorized route. Means and post hoc comparisons for EYEMAP/NAV variable are shown in Table 10.

Link value probability analysis

Link value probabilities were computed to establish the strength of the relationships between the glance categories (Wierwille, 1981). The strength of the link between categories A and B is defined as the number of glance transitions from category

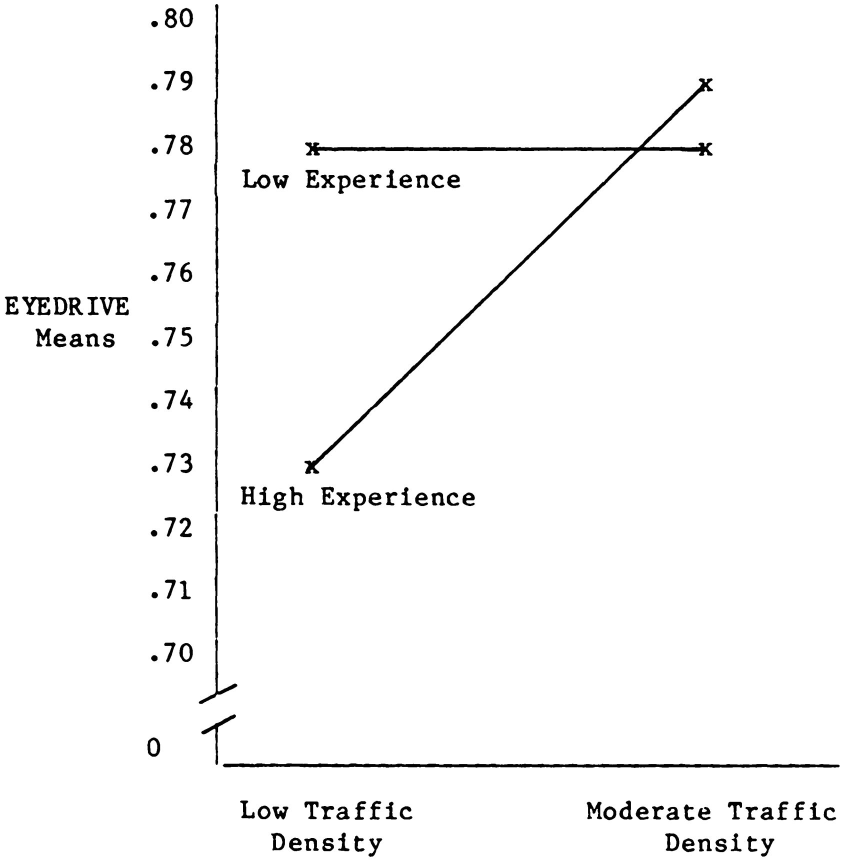


Figure 10. Traffic density-by-driving experience EYEDRIVE means.

Table 9

ANOVA on EYEMAP/NAV

Source	df	*F*	*p*
Between-Subjects			
TRAFFIC (T)	1	4.58	0.0428
EXPERIENCE (E)	1	1.60	0.2181
GENDER (G)	1	0.50	0.4881
T x E	1	1.81	0.1911
T x G	1	1.88	0.1833
E x G	1	0.41	0.5262
T x E x G	1	0.00	0.9906
SUB/T x E x G	24		
Within-Subject			
METHOD (M)	2	247.00	0.0001
T x M	2	1.65	0.2037
E x M	2	0.56	0.5727
G x M	2	0.12	0.8835
T x E x M	2	1.71	0.1911
T x G x M	2	0.71	0.4985
E x G x M	2	0.29	0.7509
T x E x G x M	2	0.35	0.7055
M x SUB/T x E x G	48		
TOTAL	95		

Table 10

Means and Newman-Keuls Post Hoc Comparisons on EYEDRIVE, EYEMAP/NAV

Navigation Method	Variable	
	EYEDRIVE	EYEMAP/NAV
Memorized Route	0.898(A)	0.000(C)
Paper Map	0.815(B)	0.068(B)
Navigator	0.602(C)	0.331(A)

Means with same letter are not significantly different ($\underline{\alpha} = 0.05$).

A to category B, plus the number from category B to A, relative to the total number of transitions. Thus, since there are seven glance categories, there are 21 link value probabilities, which, by definition, sum to unity.

Three of these link value probabilities were summed to create a variable, DRIVELINK, which is analogous to the variable EYEDRIVE, but DRIVELINK is comprised of link value probabilities, not glance probabilities. The similarity is that these three probabilities reflect the strength of the links between the glance categories used to define EYEDRIVE (roadway, mirrors, and instruments). In the same way, the sum of these probabilities is felt to indicate the strength of the links purely related to the main driving task. An ANOVA was performed on DRIVELINK and it showed that the main effect of navigation method was significant. Results are shown in Table 11.

A post hoc comparison of the means revealed that the three navigation methods were significantly different from one another; the order from highest to lowest was: memorized route, paper map, then navigator. Results are shown in Table 12.

The ANOVA in Table 11 also shows that the traffic density-by-navigation method interaction was significant. This is depicted graphically in Figure 11.

For the purposes of description and comparison, glance and link value probability diagrams, as a function of method, gender, age, traffic density, and driving experience were developed. To avoid clutter, glance and link value probabilities less than 0.01 were deleted; also glance probabilities and links with the other category were deleted. These diagrams appear in Figures 12 through 22.

Table 11

ANOVA on DRIVELINK

Source	df	*F*	*p*
Between-Subjects			
TRAFFIC (T)	1	0.60	0.4478
EXPERIENCE (E)	1	3.69	0.0668
GENDER (G)	1	2.47	0.1288
T x E	1	3.60	0.0699
T x G	1	0.08	0.7788
E x G	1	0.47	0.4982
T x E x G	1	0.00	0.9734
SUB/T x E x G	24		
Within-Subject			
METHOD (M)	2	99.56	0.0001
T x M	2	4.94	0.0112
E x M	2	0.21	0.8136
G x M	2	1.18	0.3165
T x E x M	2	0.52	0.5964
T x G x M	2	0.33	0.7229
E x G x M	2	0.40	0.6725
T x E x G x M	2	1.64	0.2054
M x SUB/T x E x G	48		
TOTAL	95		

Table 12

Means and Newman-Keuls Post-Hoc Comparisons on DRIVELINK

Navigation Method	Variable DRIVELINK
Memorized Route	0.525(A)
Paper Map	0.334(B)
ETAK	0.144(C)

Means with same letter are not significantly different ($\underline{\alpha}$ = 0.05).

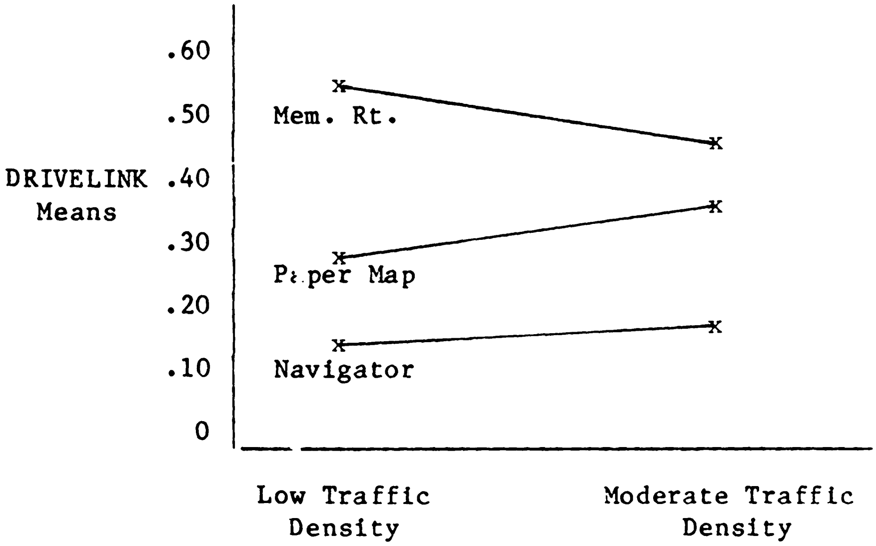
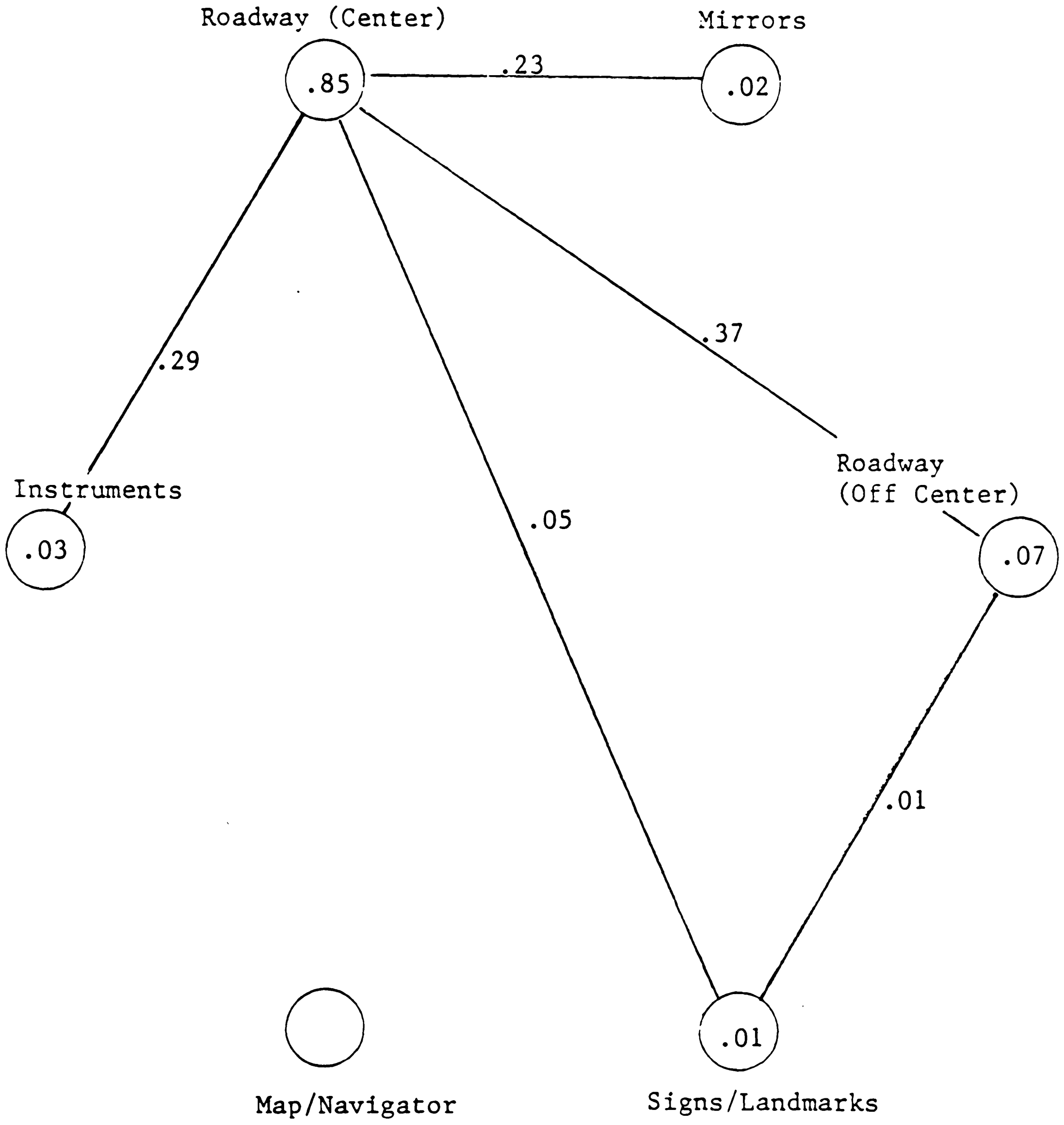
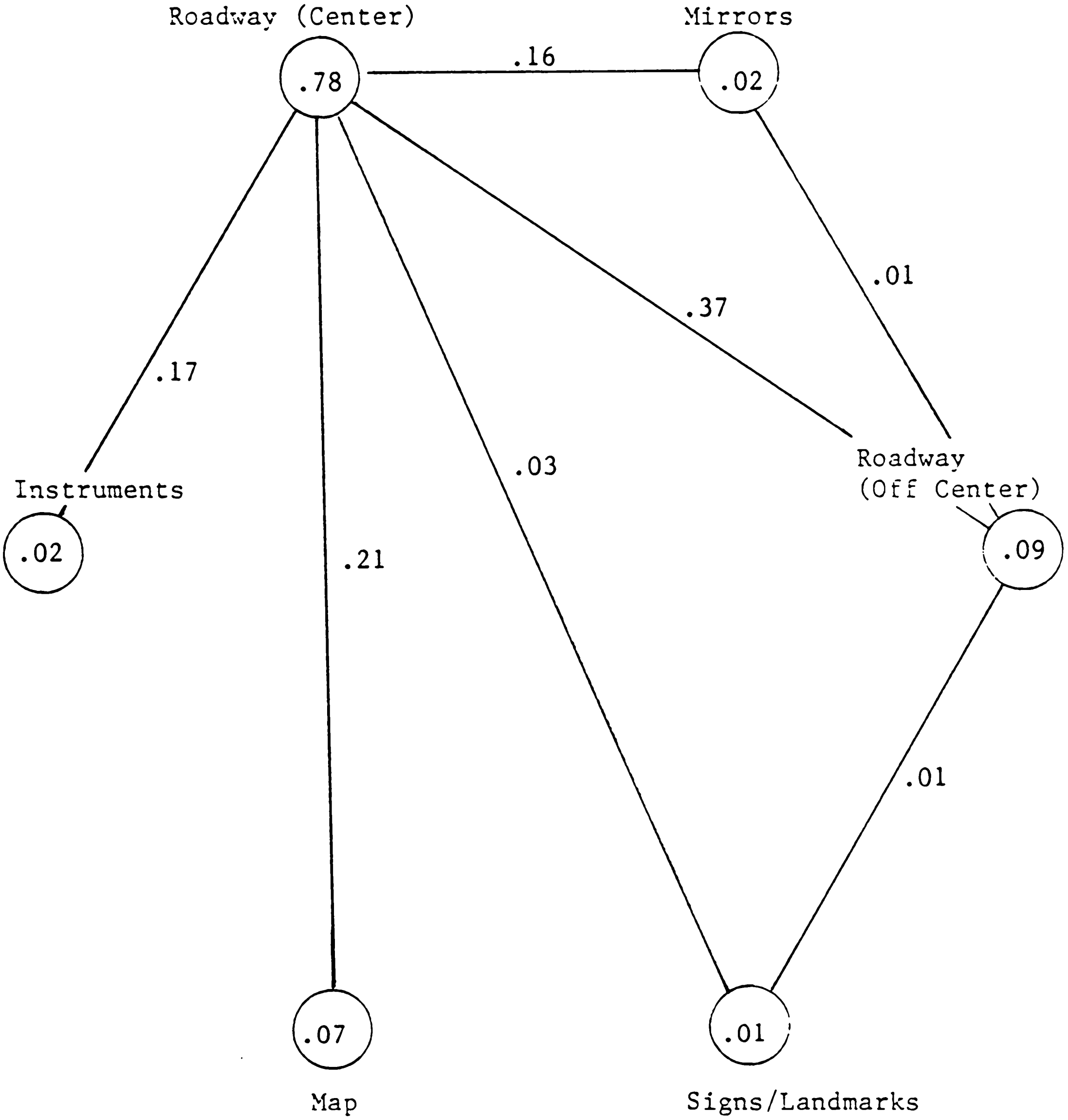


Figure 11. Traffic density-by-navigation method DRIVELINK means.



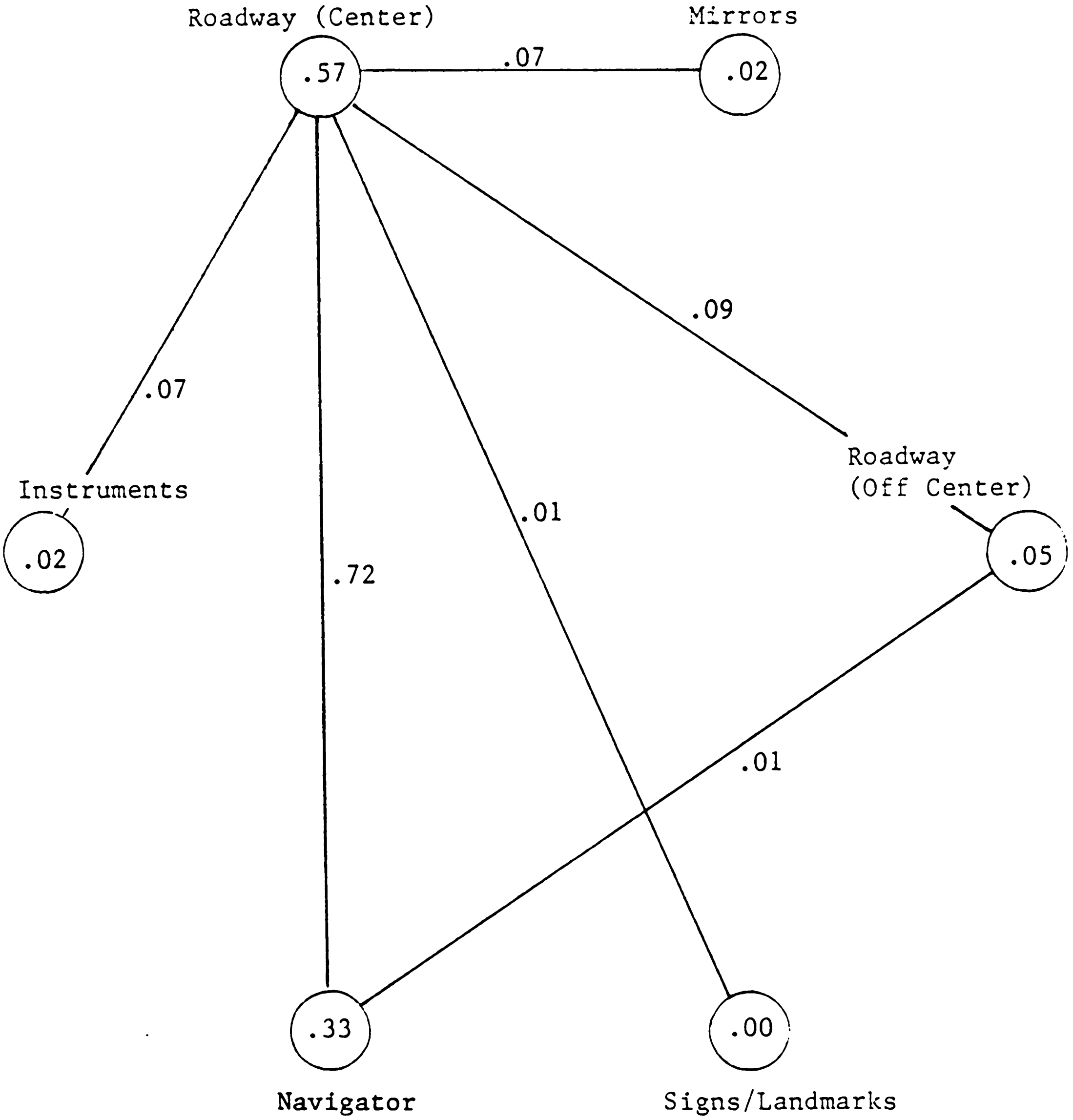
-- Circled numbers are glance probabilities.
-- Other numbers are link value probabilities.
-- Probabilities less than 0.01 are not shown.

Figure 12. Glance and link value probability diagram (Memorized route).



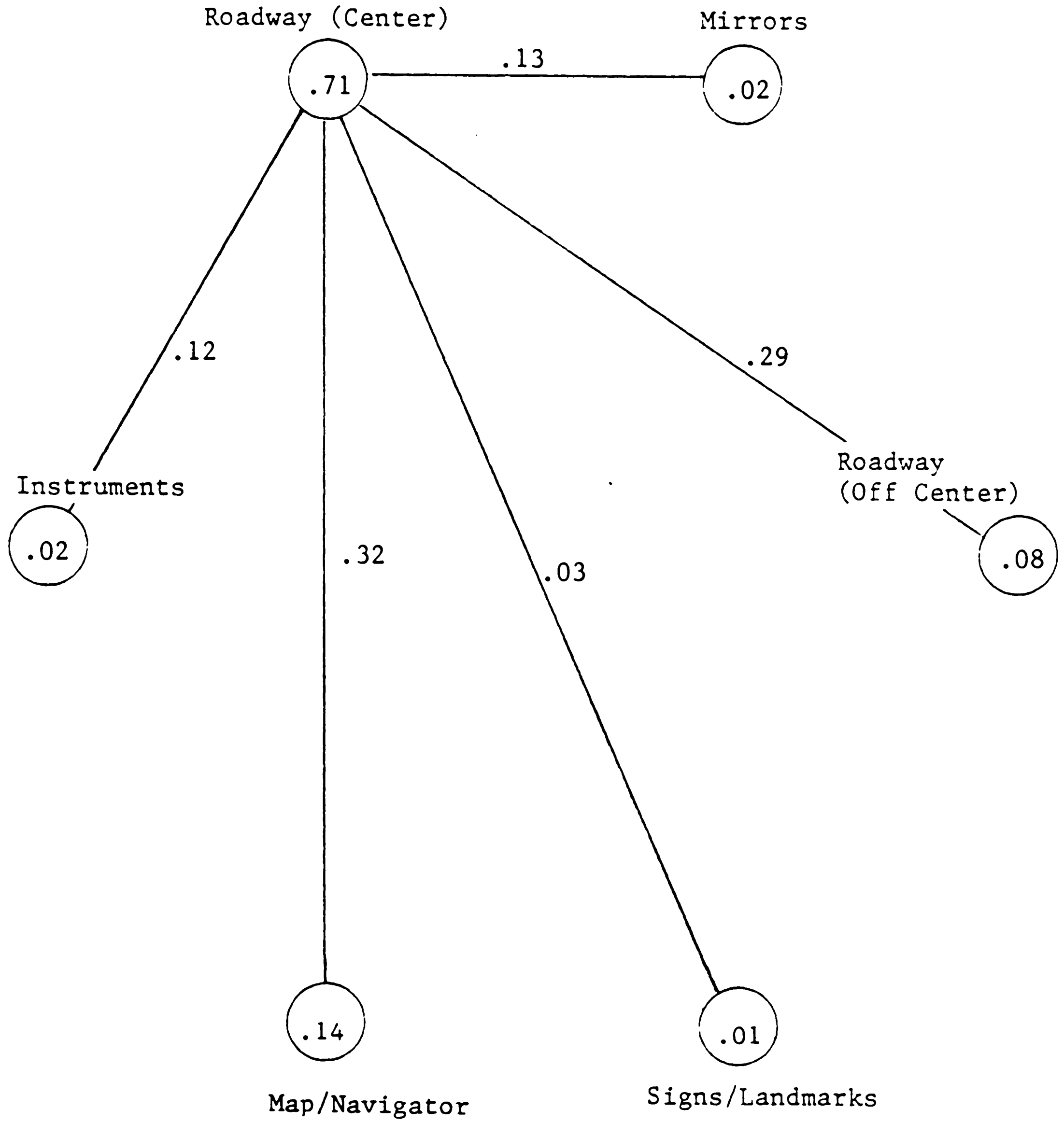
-- Circled numbers are glance probabilities.
-- Other numbers are link value probabilities.
-- Probabilities less than 0.01 are not shown.

Figure 13. Glance and link value probability diagram (Paper map).



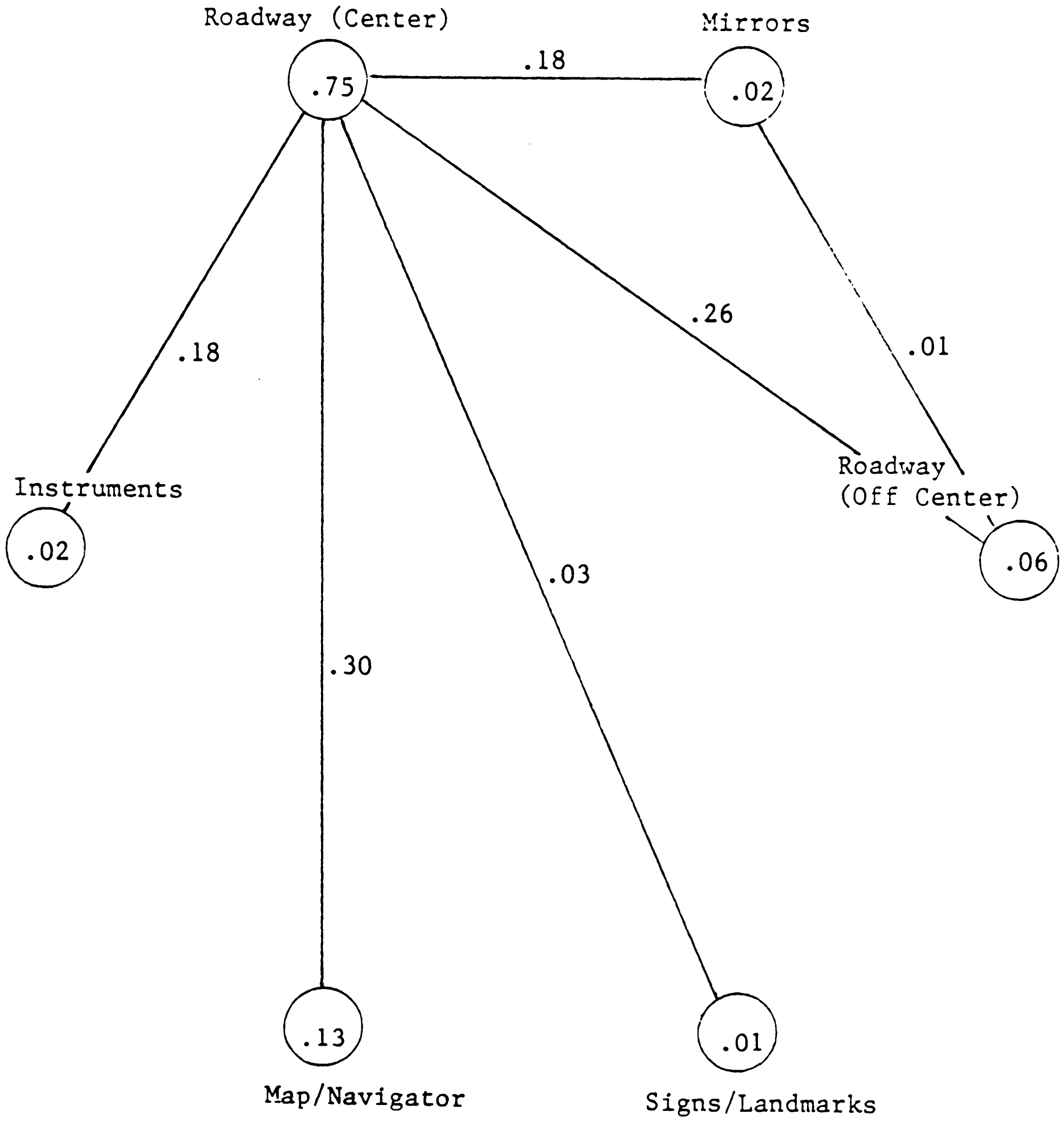
-- Circled numbers are glance probabilities.
-- Other numbers are link value probabilities.
-- Probabilities less than 0.01 are not shown.

Figure 14. Glance and link value probability diagram (Navigator).



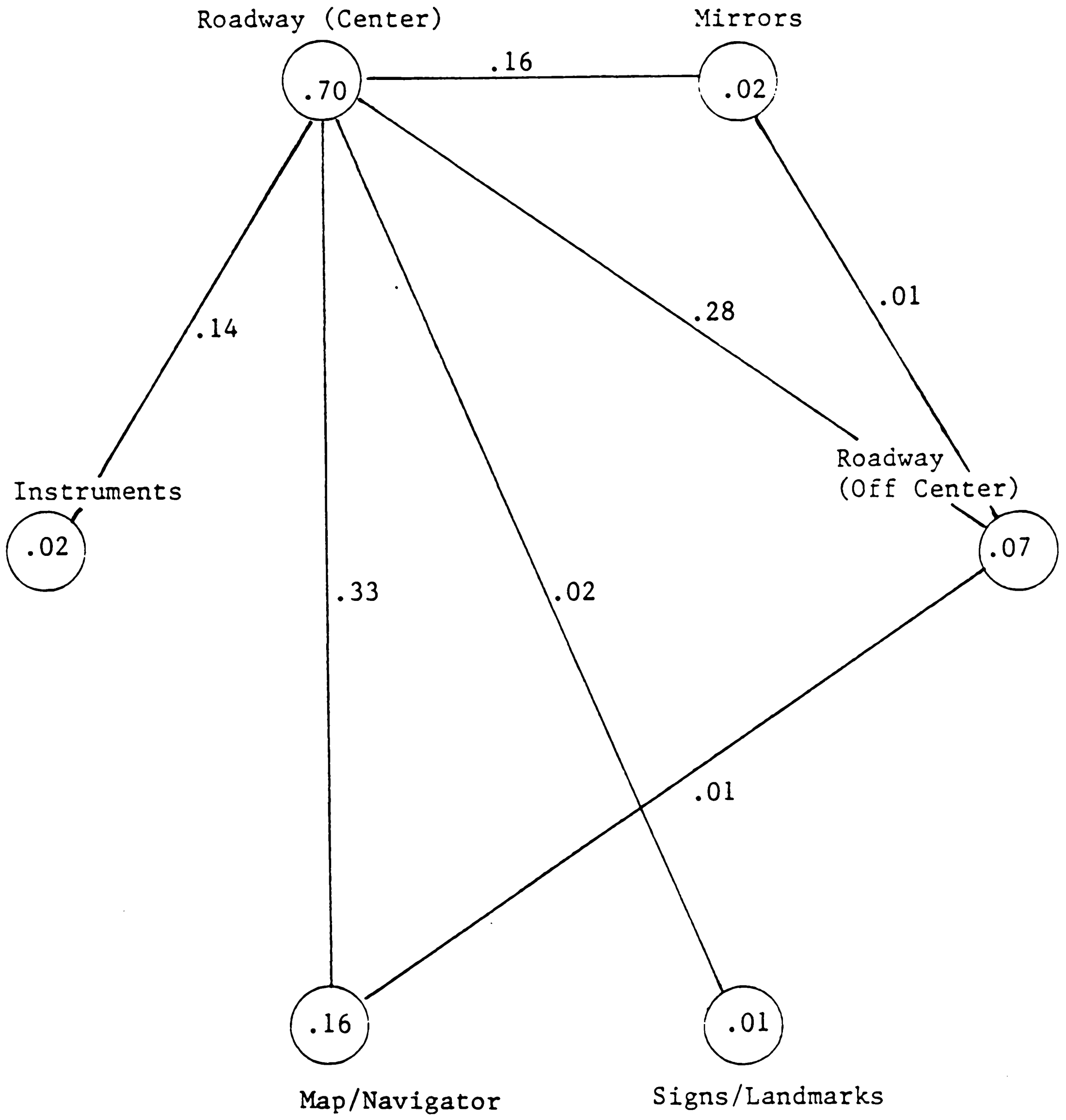
-- Circled numbers are glance probabilities.
-- Other numbers are link value probabilities.
-- Probabilities less than 0.01 are not shown.

Figure 15. Glance and link value probability diagram (Male).



-- Circled numbers are glance probabilities.
-- Other numbers are link value probabilities.
-- Probabilities less than 0.01 are not shown.

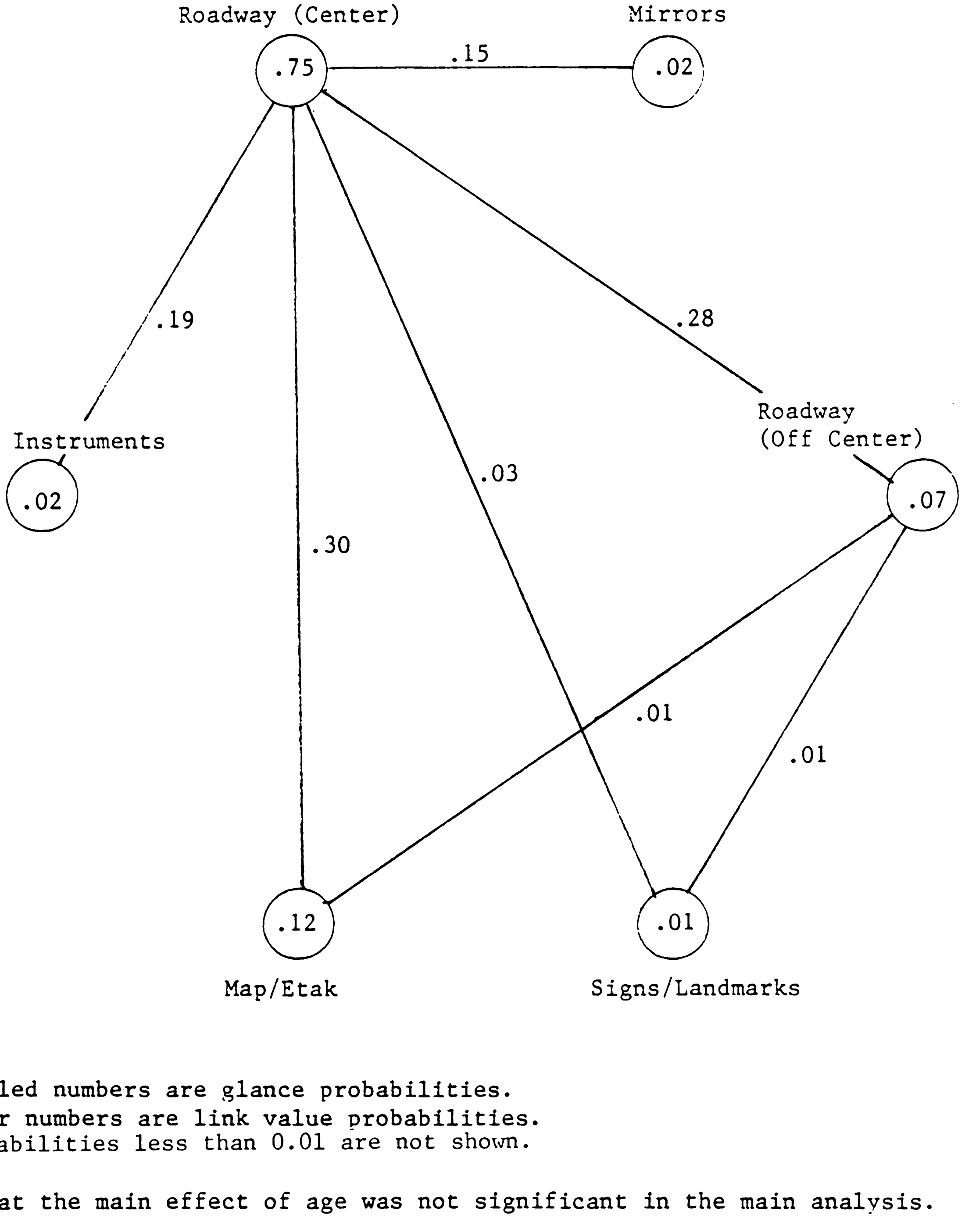
Figure 16. Glance and link value probability diagram (Female).



-- Circled numbers are glance probabilities.
-- Other numbers are link value probabilities.
-- Probabilities less than 0.01 are not shown.

Note that the main effect of age was not significant in the main analysis.

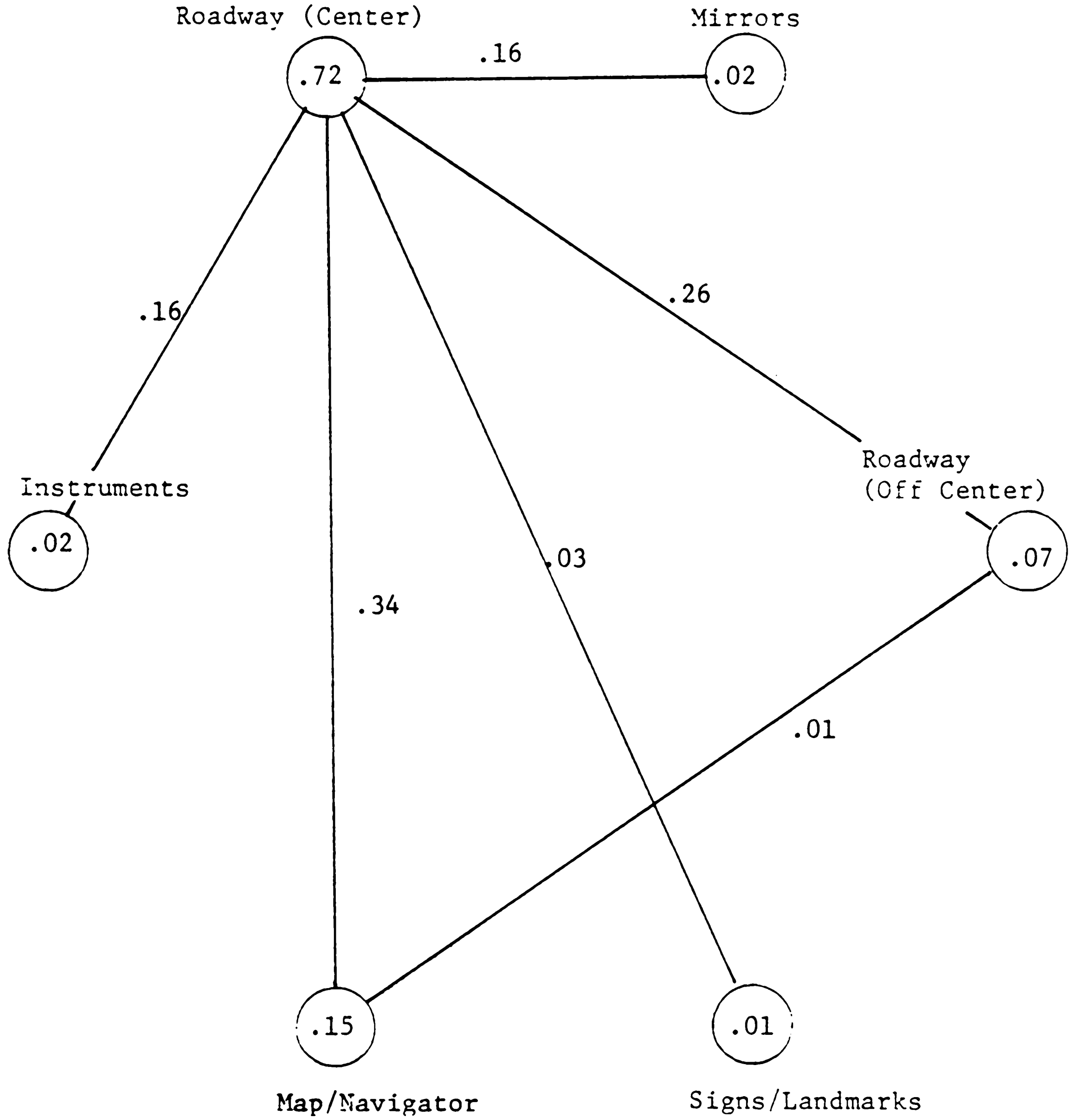
Figure 17. Glance and link value probability diagram (> 50 yrs).



-- Circled numbers are glance probabilities.
-- Other numbers are link value probabilities.
-- Probabilities less than 0.01 are not shown.

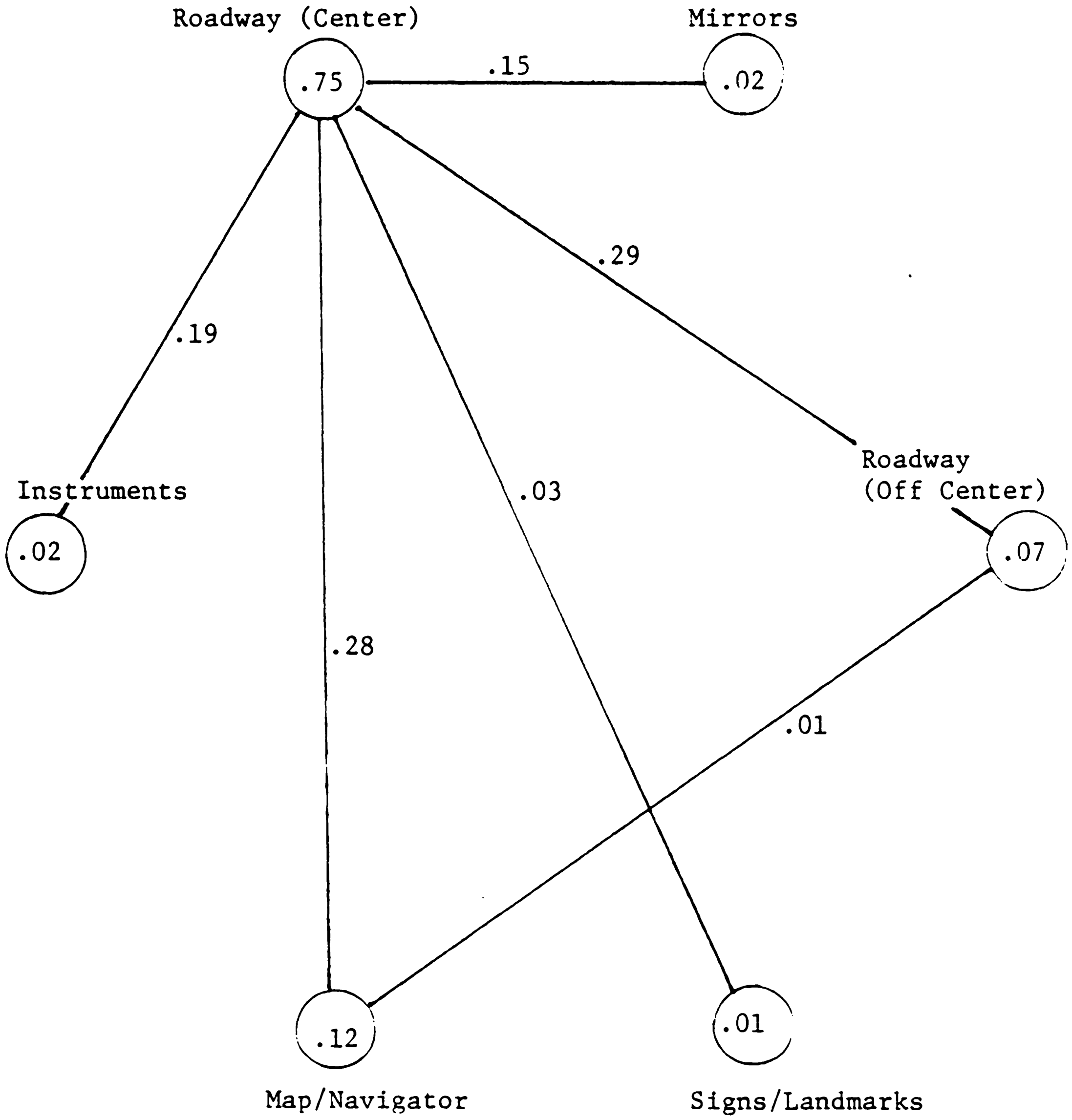
Note that the main effect of age was not significant in the main analysis.

Figure 18. Glance and link value probability diagram (< 50 yrs).



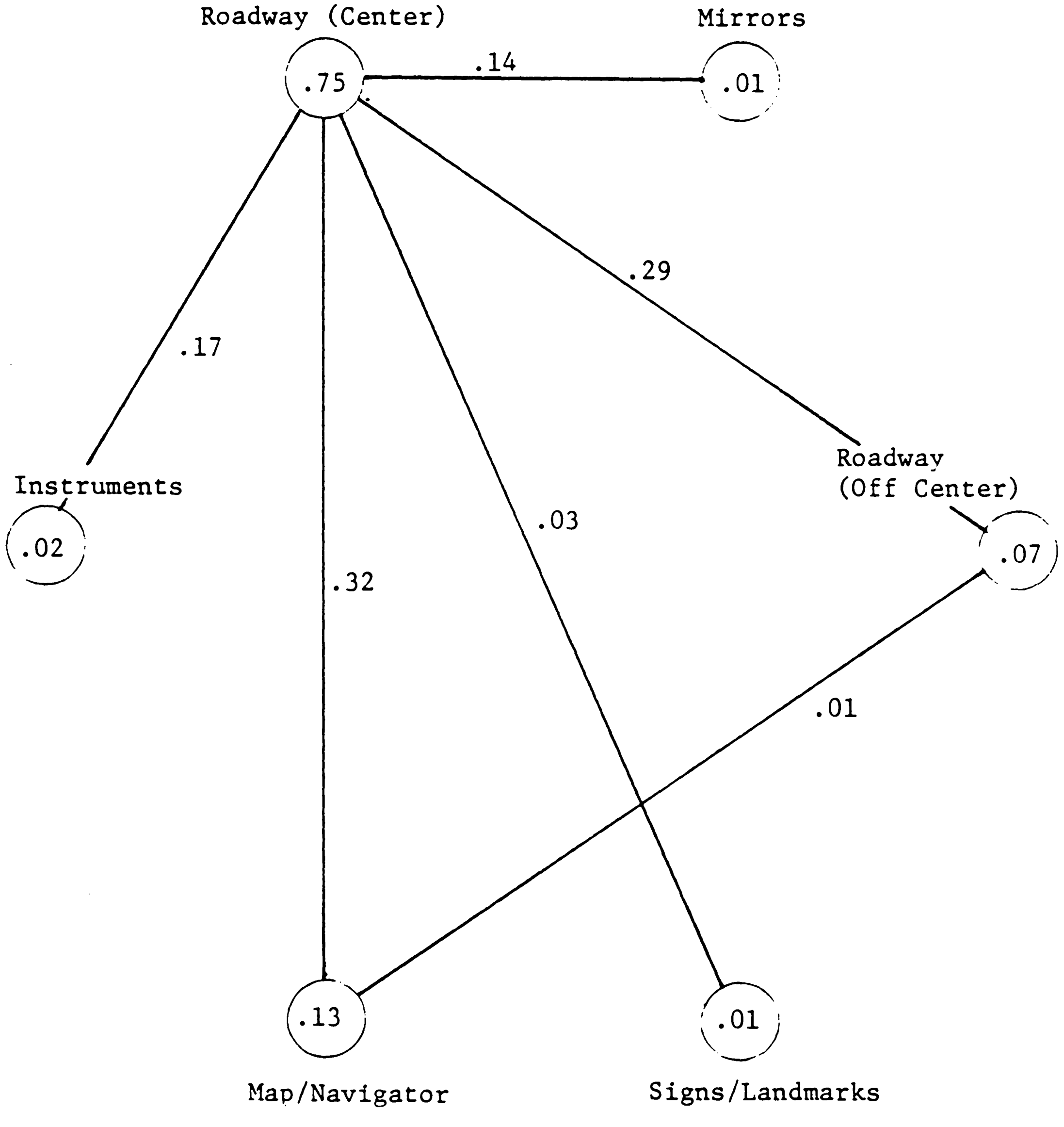
-- Circled numbers are glance probabilities.
-- Other numbers are link value probabilities.
-- Probabilities less than 0.01 are not shown.

Figure 19. Glance and link value probability diagram (low traffic density).



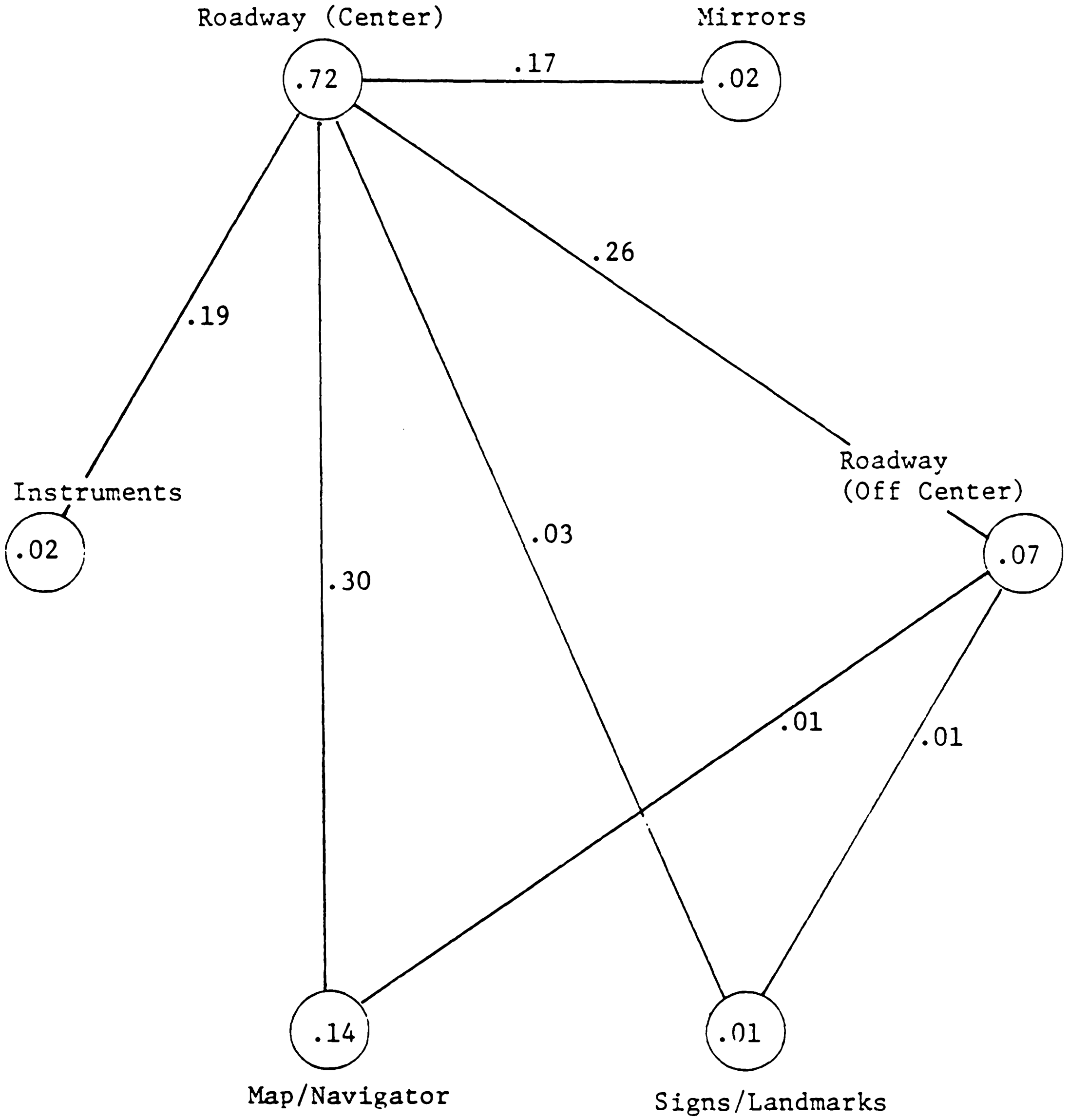
-- Circled numbers are glance probabilities.
-- Other numbers are link value probabilities.
-- Probabilities less than 0.01 are not shown.

Figure 20. Glance and link value probability diagram (high traffic density).



-- Circled numbers are glance probabilities.
-- Other numbers are link value probabilities.
-- Probabilities less than 0.01 are not shown.

Figure 21. Glance and link value probability diagram (low driving experience).



-- Circled numbers are glance probabilities.
-- Other numbers are link value probabilities.
-- Probabilities less than 0.01 are not shown.

Figure 22. Glance and linke value probability diagram (high driving experience).

Intrusion analysis

Various measures of driving quality were taken to investigate the intrusion of each of the methods of navigation on driving performance compared to the memorized route method which is considered a baseline condition. In addition to the factors already discussed, these measures were further grouped by road type. The measures of driving quality included:

%brake, which was the percent time that the brake light was activated; and %lane, which was the percent time that the vehicle was on or outside the lane boundary.

The following driving quality measures were computed per glance and then averaged for each run:

%steering exceedence was the percent time that the steering wheel rotational velocity was above 22 degrees of arc per second; %steering zero was the percent time that the steering wheel rotational velocity was below 2 degrees of arc per second; root mean square (RMS) steering velocity; RMS accelerator velocity; and high pass accelerator position variance (HPAPV). The last measure, HPAPV, was computed by using a high pass filter to attenuate the low frequencies of the accelerator position signal. This had the effect of removing the gradual shifts in accelerator position, while leaving intact the information indicating the more rapid changes.

A MANOVA was performed on the measures of driving quality, and results revealed that the main effects of navigation method and road type, as well as the method-by-road type and gender-by-road type interactions, were significant. A summary of the results is shown in Table 13.

Table 13

MANOVA on Measures of Driving Quality

Source	df	*F*	*p*
Between Subjects			
TRAFFIC (T)	1	1.28	0.3166
EXPERIENCE (E)	1	0.41	0.8810
GENDER (G)	1	0.66	0.7008
T x E	1	0.82	0.5829
T x G	1	0.82	0.5852
E x G	1	1.37	0.2780
T x E x G	1	0.71	0.6652
SUB/T x E x G	24		
Within Subject			
METHOD (M)	2	4.93	0.0001
T x M	2	0.33	0.9886
E x M	2	0.64	0.8206
G x M	2	0.90	0.5599
T x E x M	2	1.26	0.2497
T x G x M	2	0.87	0.5956
E x G x M	2	0.56	0.8918
T x E x G x M	2	0.76	0.7100
M x SUB/T x E x G	48		
ROAD TYPE (RT)	2	19.65	0.0001
T x RT	2	0.42	0.9637
E x RT	2	1.08	0.3916
G x RT	2	1.86	0.0422
T x E x RT	2	0.80	0.6645
T x G x RT	2	0.58	0.8767
E x G x RT	2	0.59	0.8656
T x E x G x RT	2	1.08	0.3836
RT x SUB/T x E x G	48		
M x RT	4	1.83	0.0074
T x M x RT	4	0.60	0.9456
G x M x RT	4	0.74	0.8267
E x M x RT	4	0.86	0.6771
T x E x M x RT	4	1.19	0.2347
T x G x M x RT	4	1.49	0.0569
E x G x M x RT	4	0.74	0.8271
T x E x G x M x RT	4	1.00	0.4704
M x RT x SUB/T x E x G	96		
Total	287		

The dependent variables used in this analysis were also submitted to individual ANOVAs to identify which variables were the most influential contributors to the significant MANOVA results. All variables except %lane were significant for the factor of road type. %steering zero and RMS steering velocity were significant for the factor, navigation method, and only RMS steering velocity was significant for the interaction, road type-by-navigation method. The significant results from the ANOVAs are shown in Table 14.

Newman-Keuls post hoc analyses were conducted on each of these variables. With regard to navigation method, the results are as follows. The navigator produced a lower %steering zero mean than the other two navigation methods, and the navigator produced a lower mean RMS steering velocity than the memorized route condition.

Post hoc analyses were also conducted for the factor road type. Four lane highway produced a mean %brake which was significantly lower than that produced by the other two road types. %steering exceedence was significantly different for each road type: the order from lowest to highest was: four-lane highway, two-lane highway, and city street. %steering zero was also significantly different for each road type, and the order from lowest to highest was reversed. RMS steering velocity was significantly higher on city streets than on the other two road types, but the order was the same as that for %steering exceedence (as would be expected). RMS accelerator velocity was also significantly higher on city streets than on the other two road types. Finally, HPAPV was significantly different for all three road types; the order from lowest to highest was the same as that for %steering exceedence and RMS steering velocity. These means and post hoc comparisons are shown in Table 15.

The gender-by-road type interaction was significant for three of the variables: %brake, RMS accelerator velocity, and RMS steering velocity. The method-by-road type

Table 14

ANOVAs on Measures of Driving Quality (Significant Effects Only)

Source	df	% Brake	% Lane	% Steer Zero	% Steer Exceed	RMS Steer Vel	RMS Acc Vel	HPAPV
Between Subjects								
TRAFFIC (T)	1							
EXPERIENCE (E)	1							
GENDER (G)	1							
T x E	1							
T x G	1							
E x G	1							
T x E x G	1							
SUB/T x E x G	24							
Within Subject								
METHOD (M)	2			0.0001		0.0069		
T x M	2							
E x M	2							
G x M	2							
T x E x M	2							
T x G x M	2							
E x G x M	2							
T x E x G x M	2							
M x SUB/T x E x G	48							
ROAD TYPE (RT)	2	0.0001		0.0001	0.0001	0.0001	0.0001	0.0001
T x RT	2							
E x RT	2							
G x RT	2	0.0008				0.0177	0.0032	
T x E x RT	2							
T x G x RT	2							
E x G x RT	2							
T x E x G x RT	2							
RT x SUB/T x E x G	48							
M x RT	4					0.0016		
T x M x RT	4							
G x M x RT	4							
E x M x RT	4							
T x E x M x RT	4							
T x G x M x RT	4							
E x G x M x RT	4							
T x E x G x M x RT	4							
M x RT x SUB/T x E x G	96							
Total	287							

Table 15

Main Effect Means and Newman-Keuls Post Hoc Comparisons on Driving Quality Measures

Method	% Brake	% Steering Zero	% Steering Exceedence	RMS Steer Vel	RMS Acc Vel	HPAPV
Memorized Route		73.6(A)		1496.4(A)		
Paper Map		72.1(A)		1344.0(A,B)		
ETAK		68.5(B)		990.2(B)		

Road Type	% Brake	% Steering Zero	% Steering Exceedence	RMS Steer Vel	RMS Acc Vel	HPAPV
City Street	29.0(A)	59.3(C)	4.7(A)	1676.0(A)	18.4(A)	124.9(A)
Two-Lane Highway	25.2(A)	71.7(B)	2.2(B)	1141.6(B)	16.2(B)	74.9(B)
Four-Lane Highway	13.8(B)	83.1(A)	0.3(C)	1013.1(B)	16.3(B)	36.9(C)

For each measure, means with same letter are not significantly different ($\alpha = 0.05$).

interaction was significant for one variable: RMS steering velocity. The means of the significant two-way interactions are depicted graphically in Figures 23 through 26.

Subject Factors Analysis

Spatial Ability Analysis

A MANOVA was conducted to assess the affects of spatial ability on some of the key time parameters: study time, drive time, total time, and average time per glance; as well as navigation effectiveness ratings. All of these variables, except average time per glance, were standardized by route as was done in the main analysis. Subjects were placed in two groups based on a composite of their scores on the three tests of spatial ability.

The scoring procedure for these tests is described below. Raw scores for each part of each test were computed by counting the number of items correctly answered on that part of the test, and then subtracting a fraction of the number wrong on that part of the test. Items left blank were not penalized.

The factor for penalizing wrong answers was selected for each test such that guessing would not diminish or inflate the test score. Each test was comprised of multiple choice items. If there were n choices per item, then the fraction subtracted for each wrong answer was: 1/(n - 1); this procedure, on the average, makes all guesses sum to zero. For example, each item on the Identical Pictures Test required a selection from among five choices. If a subject guessed randomly, he or she would have gotten, on the average, one of every five items correct. For that one correct item, the subject would have received one

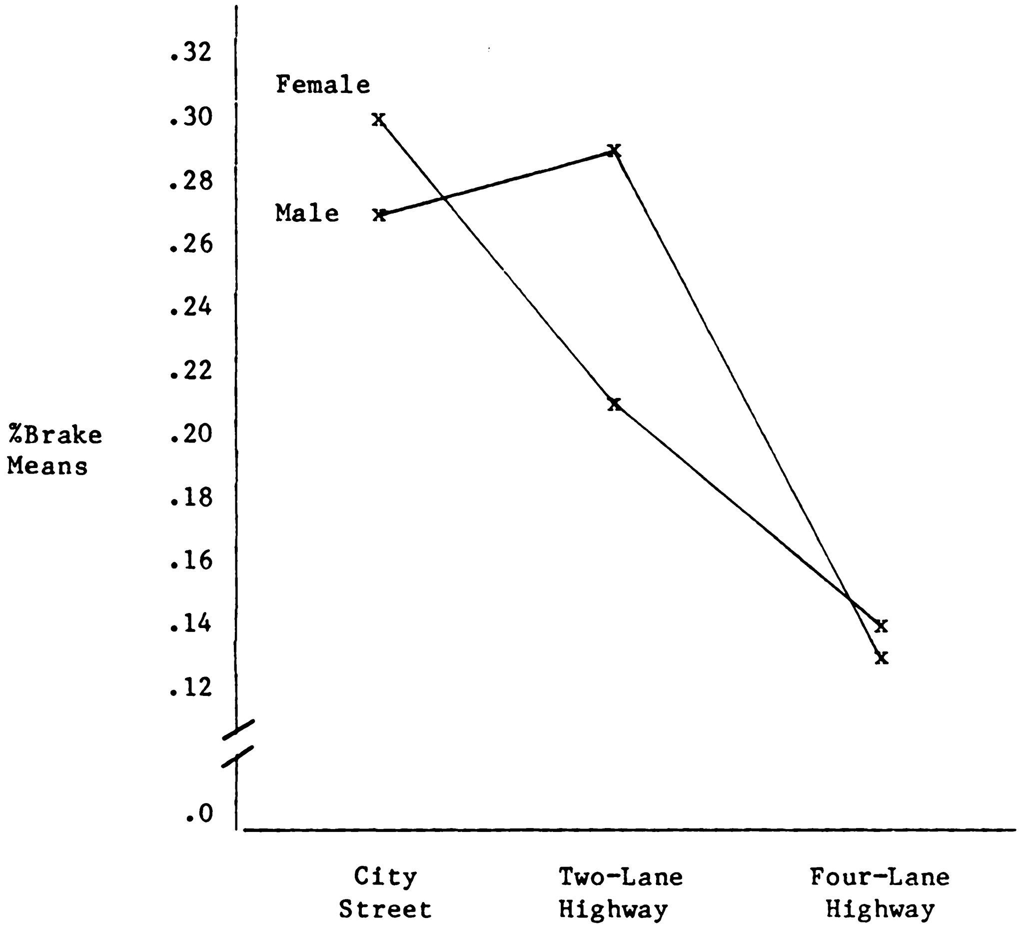


Figure 23. Gender-by-Road Type %brake means.

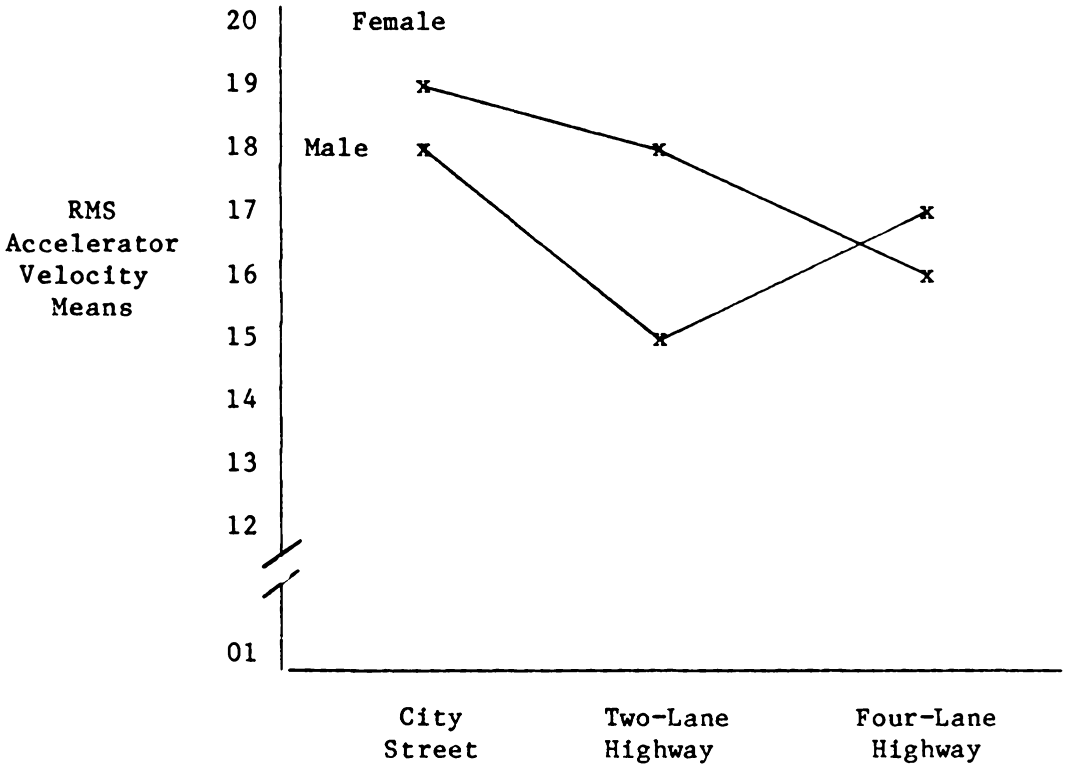


Figure 24. Gender-by-Road Type RMS accelerator velocity means.

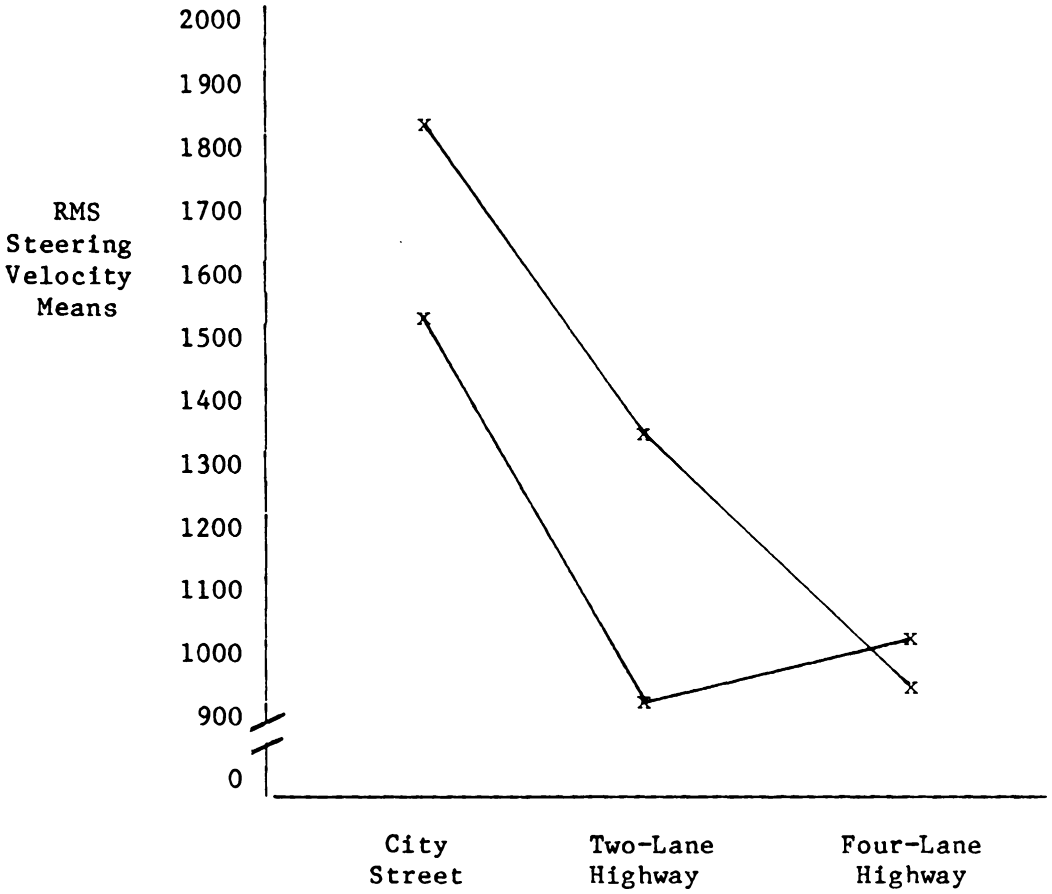


Figure 25. Gender-by-Road Type RMS steering velocity means.

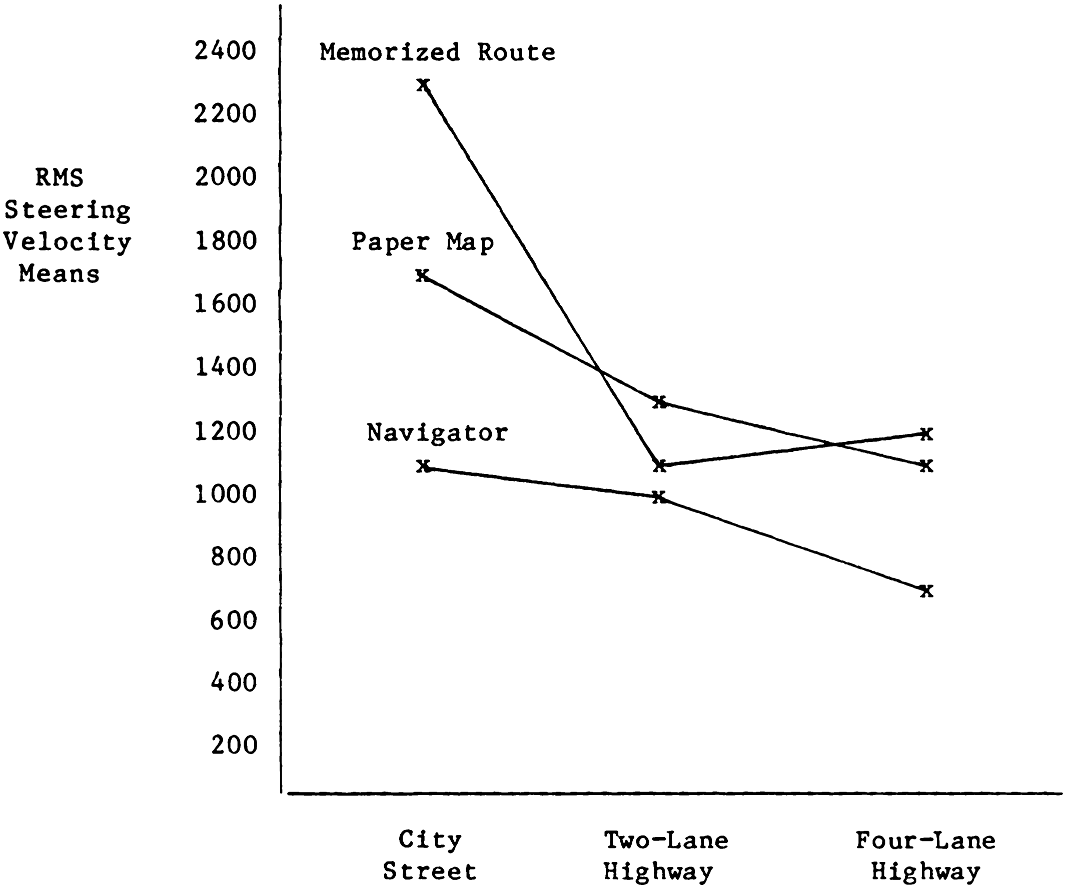


Figure 26. Method-by-Road Type RMS steering velocity means.

count, and for the four incorrect items, the subject would have had 4 × $(1/(5 - 1)) = 1$ count subtracted. Therefore, his or her score, on the average, would be zero if he or she had only guessed.

The raw score for that subject on that test was then the average of the raw scores on the two parts of that test. After the raw score was computed, then that test score was standardized with all other scores on that particular test, yielding z scores. This provided a common ground upon which a score on one test could reasonably be compared to one on another test, despite original scale differences.

The composite score for each subject was then computed by adding that subject's three standardized scores. Finally, the composite score was used to rank each subject; the sixteen highest composite scores were considered the high spatial ability group, and the sixteen lowest were considered the low spatial ability group.

Because of the post hoc nature of this spatial ability grouping procedure, the only other factors included in the MANOVA were navigation method and the spatial ability-by-navigation method interaction. The MANOVA showed that neither spatial ability nor its interaction with navigation method was significant. Results are shown in Table 16.

An ANOVA was also performed on each of the variables: EYEMAP/NAV and EYEDRIVE. The ANOVA on EYEMAP/NAV showed that the main effect of spatial ability was significant. Results are shown in Table 17.

An examination of the means reveals that subjects classified in the low spatial ability group glanced at the paper map or navigator 14.76% of the time whereas subjects in the high spatial ability group glanced at the paper map or navigator 11.84% of the time. Although the spatial ability-by-navigation method was not significant, this variable was also examined as a function of the interaction, where this same pattern was repeated for the navigator and paper map runs separately. These results are illustrated in Figure 27.

Table 16

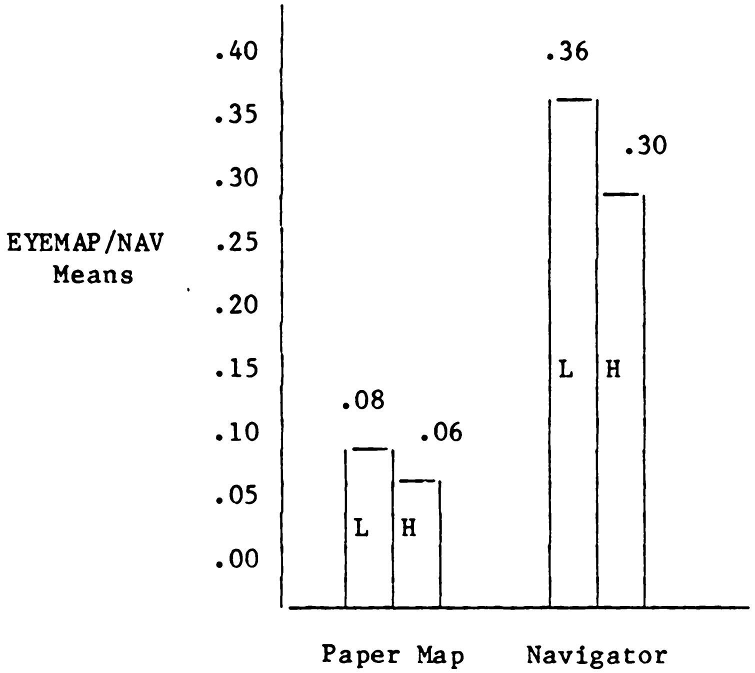
MANOVA on Spatial Ability

Source	df	*F*	*p*
Between-Subjects			
Spatial Ability (Spat)	1	0.62	0.6890
Sub/Spat	30		
Within-Subject			
Method (M)	2	27.10	0.0001
Spat x M	2	1.05	0.4073
Sub x M/Spat	60		
Total	95		

Table 17

Spatial Ability ANOVA on EYEMAP/NAV

Source	df	F	p
Between-Subjects			
Spatial Ability (Spat)	1	6.75	0.0144
Sub/Spat	30		
Within-Subject			
Method (M)	2	270.34	0.0001
Spat x M	2	2.17	0.1226
Sub x M/Spat	60		
Total	95		



L - Low spatial ability group
H - high spatial ability group

Note that the spatial ability-by-navigation method interaction was not significant.

Figure 27. EYEMAP/NAV means for high and low spatial ability groups.

The ANOVA on EYEDRIVE showed results similar to the ANOVA on EYEMAP/NAV; spatial ability was significant. Results are shown in Table 18.

The low spatial ability group produced a mean EYEDRIVE score of 75.44%, and the high spatial ability group produced a mean score of 78.94%. Again, although the spatial ability-by-navigation method interaction was not significant, an examination of the interaction means showed that the high spatial ability group produced higher EYEDRIVE scores on each of the navigation methods than the low spatial ability group. These results are illustrated in Figure 28.

Age Analysis

A MANOVA including the factor of age was performed on the measures of driving quality. So that there would not be only one subject per cell, traffic density was dropped from this analysis. Neither age nor any of the interactions involving age was significant.

A second MANOVA was performed on certain time parameters and the navigation effectiveness rating to examine the effect of age on navigation performance. Neither the main effect of age nor any of its interactions was significant.

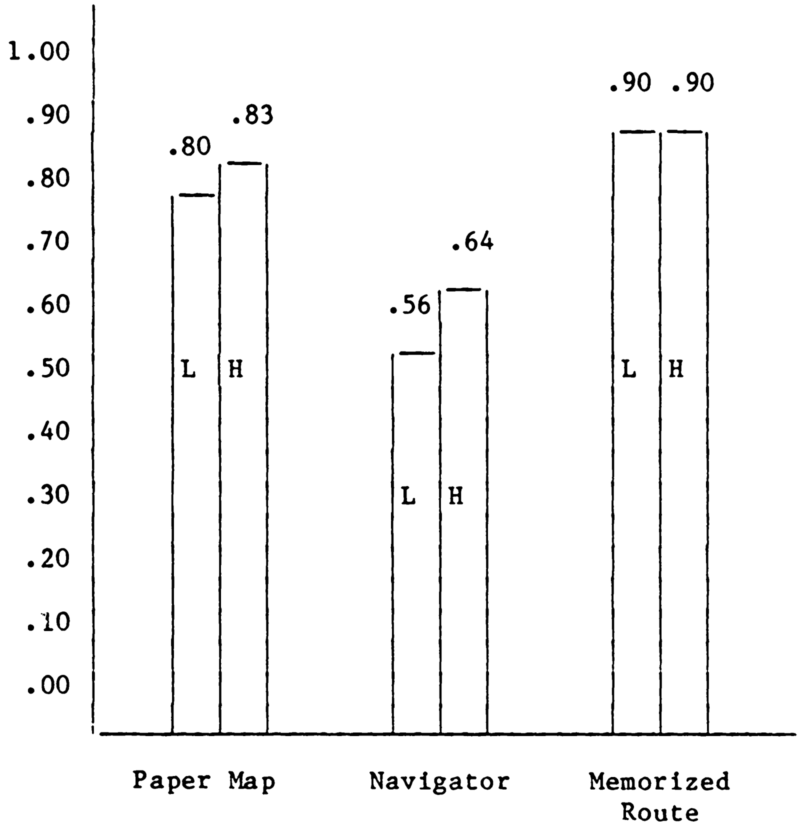
Multiple Regression Analysis

A series of multiple linear regression equations were generated using the following regressor variables: subject, age, gender, driving experience, the score on each of the three tests of spatial ability, and navigation method.

Table 18

Spatial Ability ANOVA on EYEDRIVE

Source	df	*F*	*p*
Between-Subjects			
Spatial Ability (Spat)	1	5.11	0.0312
Sub/Spat	30		
Within-Subject			
Method (M)	2	182.71	0.0001
Spat x M	2	3.05	0.0547
Sub x M/Spat	60		
Total	95		



L - Low spatial ability group
H - High spatial ability group

Note that the spatial ability-by-navigation method interaction was not significant.

Figure 28. EYEDRIVE means for high and low spatial ability groups.

The first regression model used total time (standardized by route) as the response variable, the second used the navigation effectiveness rating as the response variable; neither model yielded significant results, and both $\underline{R}^2$ values were near zero.

Questionnaire Analysis

Data generated from the questionnaire were not submitted to statistical analyses, because it is felt that these data are best used as an interpretive aid in understanding the results of the performance data. Means were generated on certain of the subjective ratings provided in the questionnaire. Ratings were provided on the degree of ease/difficulty encountered in the use of the navigator and the paper map; subjects could mark anywhere on a scale which ranged from -5 (very difficult) to 5 (very easy), (see Appendix B). The overall average ease/difficulty rating for the navigator was 2.59 compared to 2.86 for the paper map which indicates an "easy" rating for both methods of navigation.

The same rating scale was used to gather subject ratings on the ease/difficulty in maintaining the correct zoom level on the navigator. Maintaining the correct zoom level is a process whereby one continually zooms in or out to gather all relevant information regarding the most efficient path to the destination. The overall average rating provided for this parameter was 1.92, which falls in the easy to moderate range. Finally, each subject was asked to indicate which of the two methods of navigation he or she preferred. The scale was marked only with positive numerals for both methods (See Appendix B). It was felt that based on population stereotypes, and on subjects' direct experience with the other rating scales (which associated negative numbers with difficulty) negative numbers would taint the subjects' perceptions of the method represented by them. Preference ratings for the paper map were later converted to negative numbers to differentiate them from navigator preference ratings. Therefore, if the average rating were highly positive (near + 5), then the navigator would be heavily preferred, whereas if the average rating were highly negative (near -5), then the paper map would be heavily preferred to the navigator. The average overall preference rating was 2.17, and only 4 of the 32 subjects preferred the paper map.

These same variables were then averaged separately for two age groups: the 50+ group and the 49 and under group. Results showed the ease/difficulty ratings to be higher for the older group for both methods of navigation, and much higher with regard to ease/difficulty of maintaining the correct zoom level. The older subjects also preferred the navigator to the paper map more strongly than the younger group.

Finally these same variables were again averaged separately for the two genders. The average ease/difficulty ratings were very similar. One difference was that males tended to prefer the navigator more strongly than the females, even though males indicated more difficulty in the maintenance of the correct zoom level. These results are illustrated in Figures 29 through 32.

Subjects were given the opportunity to agree with any, all, or none of two sets of statements. The first set of statements presented supposed advantages of the paper map to the navigator; the second set presented supposed advantages of the navigator to the paper map. The items selected by at least one half of the subjects are listed below (although every item was selected by at least six subjects). Selected advantages of paper maps were: (1) paper maps show the entire area at once (i.e., there is no zoom-in/zoom-out with paper maps, (2) paper maps show greater detail than the navigator, and (3) paper maps can be written upon.

Advantages of the the navigator selected by at least one half of the subjects included: (1) the navigator shows the location of the vehicle on the map at all times, (2)

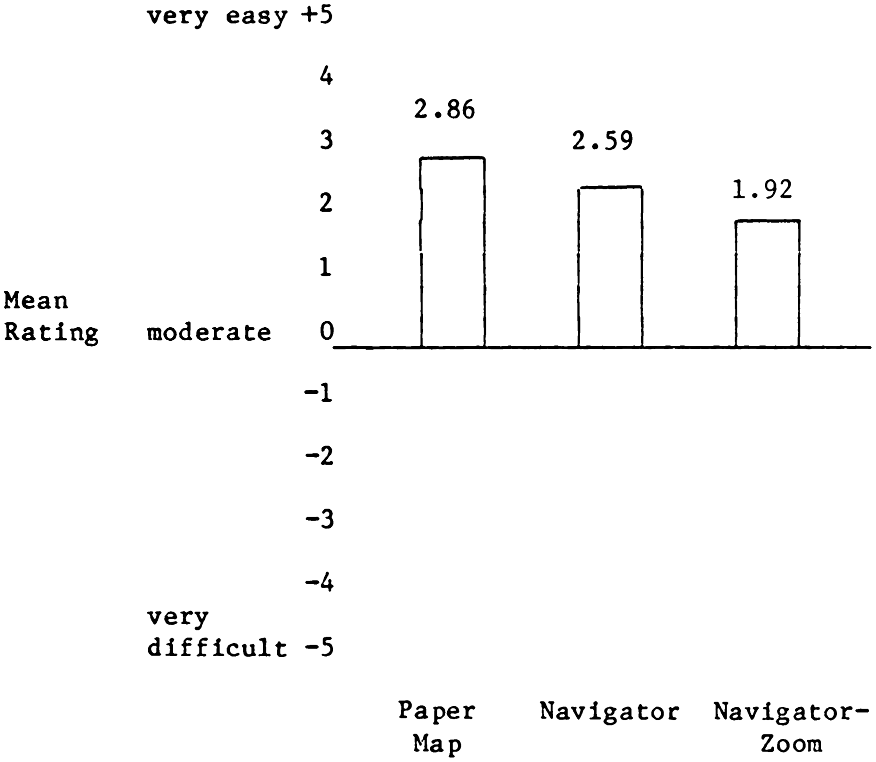


Figure 29. Mean ease/difficulty ratings (overall).

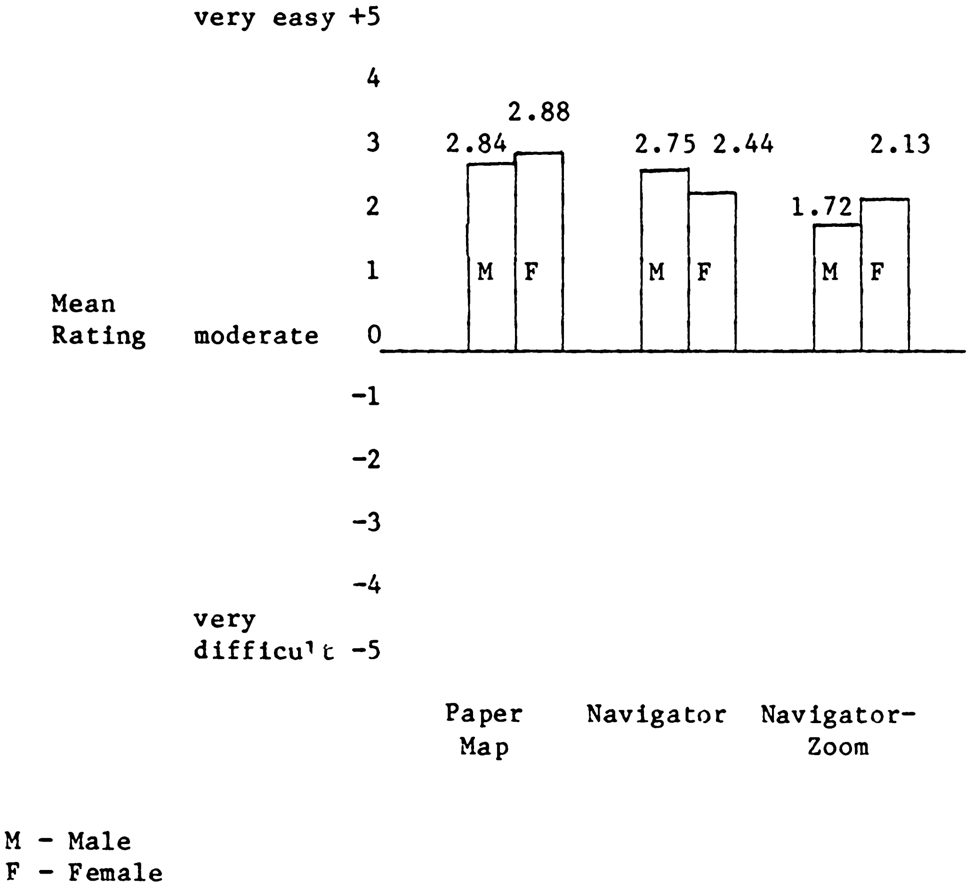


Figure 30. Mean ease/difficulty ratings (by gender).

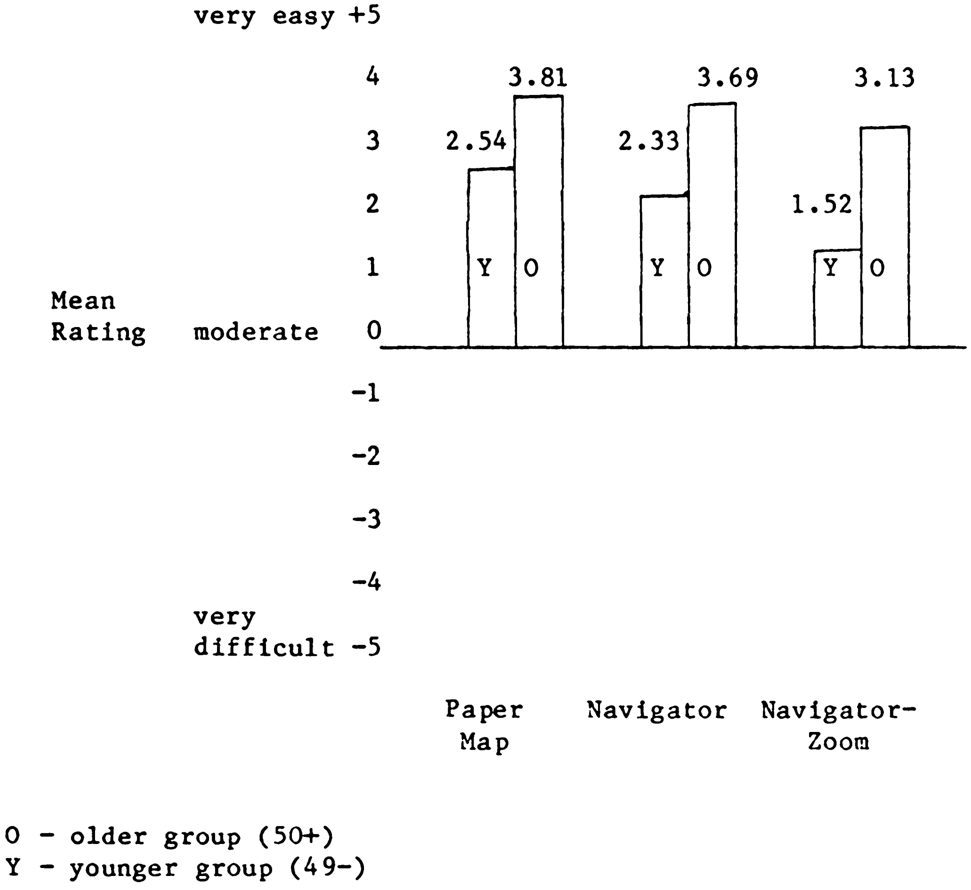


Figure 31. Mean ease/difficulty ratings (by age).

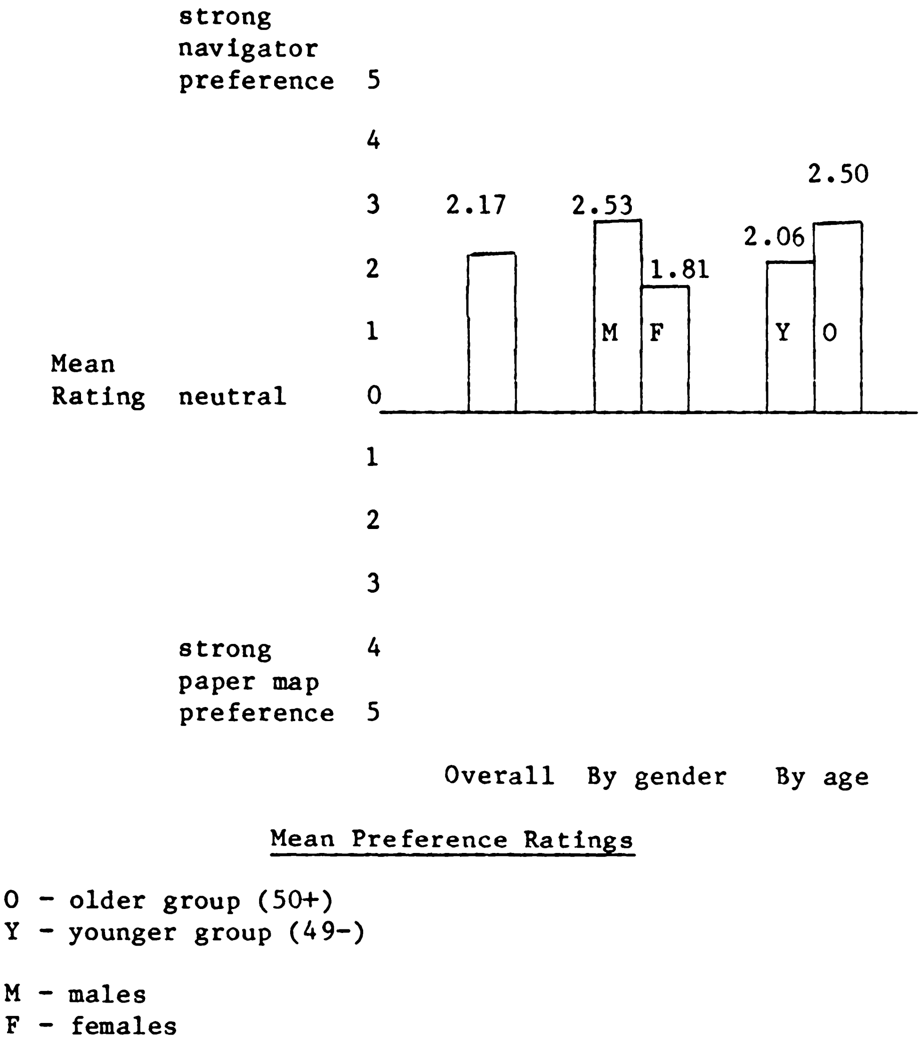


Figure 32. Mean preference rating (overall, by gender, and by age).

the navigator shows only relevant information (i.e., level of detail is determined by the chosen zoom level), (3) the navigator continually reorients the map such that your heading is always up on the display, (4) the navigator requires no folding, holding, or unfolding as does a paper map, (5) the navigator is placed such that it can be conveniently used while driving, and (6) the navigator shows the vehicle's distance to the destination at all times.

DISCUSSION

Nuisance Factors

The preliminary analysis was conducted in an effort to assess the impact of the nuisance factors on the factors of interest in the study. The main nuisance factors were route, order, and their interactions with navigation method. These are considered nuisance factors because their presence in the experimental design was unavoidable, and their effects are confounded with the factors of interest.

For example, it was necessary to use three separate routes, because when a destination was reached, that route and destination were no longer unfamiliar and no longer usable. As expected, route differences were significant for some variables. Therefore, to control for these differences, certain of the time parameters (study time, drive time, and total time) were standardized, by route, before being included in any analysis.

Order of presentation is a problem in any within-subjects experiment. One problem is fatigue; subjects′ total time in the research vehicle averaged about six hours including training and participation in the study reported in Dingus, et al. (1986). Although there were frequent short break opportunities, most subjects reported feeling somewhat fatigued, at least by the end of the session. Clearly this could have had an effect on any aspect of subject performance.

There is a second common problem associated with order of presentation, the learning or practice effect. Although it seems somewhat less likely that this had an impact on the current study, there is some evidence that performance did improve with practice. The practice effect should not be great, because the real differences in the methods of navigation should lessen the degree of transfer of training (though, admittedly, all do provide practice in automobile navigation in general). However, the subjects who did get lost only failed to reach the destination on the first run, regardless of which method they were using when they got lost, indicating the presence of a practice effect.

In general, the positive influence of the practice effect tends to work against the negative influence of fatigue, though the relative influence of each in the present study is unknown. Also, the counterbalancing scheme employed should distribute any order effect relatively evenly across the three navigation methods, since there was no differential transfer. This was shown by the lack of a significant navigation method-by-order interaction.

Navigation Effectiveness and Strategy

The first set of analyses examined the time-dependent parameters. The only significant factor was navigation method. Neither gender, driving experience, traffic density, nor their interactions had an effect on this set of dependent measures.

The question remains as to which dependent measures contributed to the significant method effect and in which direction. Study time, the time taken from the signal given to begin until the car was put in gear, was shortest for the memorized route condition (close to zero in every case). There was no map or navigator to be studied in this condition. The time taken to study the paper map was, on average, twice that taken to study the navigator (92.78 and 45.04 sec, respectively). This result is one key in understanding the differences between navigating with a paper map vs. navigating with the navigator. A paper map can be used to study and plan one's entire route from start to destination, in as great detail as is desired. One can only plan a general route when using the navigator; this is because detailed information is presented only in the area immediately surrounding the current location of the vehicle.

Despite the extra preplanning, there was no significant difference in mean drive times for the paper map and navigator (14.00 vs. 15.20 min, respectively). Drive time was the time taken from when the car was put into gear, until the destination was reached. There was no significant difference between the paper map and navigator conditions on the total time variable (15.55 vs. 15.95 min, respectively).

These numbers are interesting; they indicate that the extra time taken to study the paper map before a run was made up by the extra time taken to use the navigator during a run. Various factors pertaining to attentional demand may have contributed to this phenomenon.

One possibility is that it took longer per glance to derive the necessary information from the navigator than from the paper map. The opposite was the case; results showed the average time per glance (to the map or display) to be 1.52 sec for paper map and 1.37 sec for the navigator, though this difference was not significant.

A second possibility is that subjects used the navigator more frequently than the paper map while driving. Results showed that this was indeed the case as subjects spent an average of 33.07% of driving time looking at the navigator, compared to 6.79% looking at the paper map.

A related measure told a similar story. EYEDRIVE was a measure of the fraction of time spent glancing only at things directly concerned with the driving of the vehicle (i.e., excluding such things as navigation). This variable showed that, when relatively unburdened, (i.e., the route was memorized and there were few distractions of any kind) subjects spent 89.84% of the time glancing at things directly concerned with the driving of the vehicle. When using the paper map the average EYEDRIVE dropped to 81.49%, and it dropped further still to 60.23% when using the navigator. It is interesting to note that the decreases in EYEDRIVE (8.35% and 29.61% for the paper map and navigator respectively) correspond closely to the percent time spent looking at the paper map and navigator (6.79% and 33.07%, respectively). Average time/glance in general showed that the number of glances per unit time increased when using the navigator (i.e., average time/glance decreased). This was likely due to the frequent glances from the roadway to the navigator and back.

These figures are not surprising, at least in direction if not in magnitude. It was argued earlier that one of the important differences between paper maps and navigational displays is the greater ease of use of the navigational display while driving; the convenient location of the navigator in the dashboard lends itself to frequent use. For any single glance, this should be an advantage as the eyes are not drawn as far away from the roadway(center) as they presumably would be when looking at the paper map. However, because of the lack of detailed information anywhere but around the vicinity of the vehicle's current location, frequent use of the navigator is required for navigation -- much more frequent use than is required when using a paper map. New, detailed information is continually provided as the destination is approached; this information must be attended to if navigation is to be effective (i.e., if wrong or missed turns are to be avoided).

The above two aspects of time-sharing have been discussed in an effort to explain why the paper map produced shorter drive and total times than the navigator (though neither measure was significant), even though the paper map produced significantly longer study times. An issue not directly related to time-sharing is navigation effectiveness. This deals with the directness of the route selected by the subject, missing or making wrong turns, and, of course, whether or not the subject reached the destination. However, navigation effectiveness ratings, when standardized by route, showed that the slightly higher ratings produced by the paper map were not significantly higher than those produced by the navigator; the non-standardized ratings were identical. Therefore, this measure does not help explain how time lost in the initial study of the paper map was regained in the course of actually navigating along the route.

A fourth possibility is that the paper map was more efficient to use during a run because it could be more effectively studied during natural traffic stops (e.g., red traffic lights and stop signs). This would be the case for the same reason that it took longer to study the paper map before a run; the paper map shows maximum detail at <u>all</u> points, whereas the navigator only shows detail in the area immediately around the current location. Therefore, this would seem to be an advantage of the paper map over the navigator. It must be noted that since eye movement data were not gathered while the vehicle was stopped, and subjects were free to stop at any point to reorient themselves, it may seem as if key information is missing: namely what navigation behavior was exhibited while stopped. This information may be especially interesting with regard to the paper map, since, it has been argued, the paper map can be used more effectively for long range planning while the vehicle is stopped. However, if subjects did spend more time being voluntarily stopped, this would have been manifested in longer average drive times and total times, which was not the case.

The above discussion focuses mainly on the differences in strategy adopted by users of paper maps compared to users of a navigational display. The behaviors exhibited in the memorized route condition are also of great interest, since they show the strategy of drivers under typical driving conditions. The most useful data in this regard are the glance and link value diagrams: Figure 12, and Figures 15 through 22.

Figure 12 shows that when in a relatively familiar environment, the driver spends the great majority of time looking at the forward roadway. The link between roadway (center) and roadway (off center) is the strongest, and links from the roadway (center) to the mirrors and the instrument cluster are also relatively strong.

Recall here that glance probabilities associated with glances to the roadway (off center) were not included in the EYEDRIVE variable, because this variable was to reflect the time spent glancing to items strictly associated with the driving of the vehicle. It was assumed that glances to the roadway (off center) could also be interpreted as a search for navigation clues. The fact that the roadway (off center) category figures so strongly in Figure 12 is consistent with this notion; no matter how well learned a route becomes, the cues which guide one along the route must still be seen and perceived to be of use. This points to an interesting difference among the glance and link value probability diagrams for the three navigation methods; the strongest link for the map condition as well as for the memorized route condition is the link between the roadway (center) and the roadway (off center). This particular link is much weaker for the navigator condition indicating that the subjects were looking to the display for navigation information much more so than to the outside world.

An examination of the glance and link value probability diagrams grouped by age, gender, driving experience, and traffic density showed only minor differences. The differences that did appear suggested that low experience drivers, drivers in heavier traffic densities, females, and younger subjects (under 50) tend to drive somewhat more conservatively than high experience drivers, drivers in lower traffic densities, males, and older subjects, respectively. Conservatism is felt to increase when the glance categories relating to driving and the associated link value probabilities increase, and when the attention paid to navigation decreases.

The fact that all of the diagrams (excluding the ones grouped by navigation method) were very similar paints a very clear picture of the glance pattern that is displayed when driving, despite subject or environmental differences.

Intrusion

Results showed that there was some intrusion of the navigation methods on driving performance in general. This was primarily indicated by two of the steering parameters. %steering zero showed that there were fewer steering wheel holds while using the navigator.

McDonald and Hoffman (1980) posited that steering wheel reversal rate (SRR) increased with driving demands up to the point where task demands exceed driver capabilities. As demands increase beyond capabilities, SRR begins to decrease as time-sharing becomes less and less efficient resulting in the neglect of the steering task. Therefore, taking the position offered by McDonald and Hoffman (1980) leads to the conclusion that the use of the navigator was more distracting than the other two methods of navigation, but still within operator capability. Also it is possible that simply reaching for the navigator with the right hand while holding on to the steering wheel with the left could result in some slight inadvertant steering movements; subjects actuated the zoom-in function an average of 9.78 times, and the zoom-out an average of 4.69 times during the navigator runs.

The other significant variable was RMS steering velocity; it showed that the navigator produced lower velocity movements than were produced in the memorized route condition. It is difficult to rationalize this result with the fact that there were fewer steering holds while using the navigator. Also, these results may have been an artifact of the slight imbalance in the counterbalancing scheme.

It is important to note that neither the lane exceedence measure (%lane) nor the brake usage measure (%brake) nor the accelerator measures (RMS Accelerator Velocity; HPAPV) changed.significantly as a function of navigation method. The lack of systematic changes with method suggests that drivers adapted readily to different types of navigation and that driving performance did not change substantially. Another way of saying this is that drivers attended to navigation (when using the paper map or the navigator) primarily using spare capacity.

Dingus et al. (1986) found changes in the number of lane exceedences as a function of the instructed tasks. In the current study there were none as a function of method. This apparent difference can be reconciled by noting that drivers were not commanded to perform specific detailed tasks in this study. Consequently, they were free to choose their own opportunities to update their navigation information. As a result, they apparently did not allow the driving task to deteriorate.

Environmental Factors

Road type

The four-lane highway produced better or easier driving than the the other two road types in terms of requiring fewer and smoother control inputs. City streets produced the opposite result, proving more difficult to negotiate than the other two road types in general.

The four-lane highway produced less brake actuations than the other two road types, fewer steering inputs above threshold, and lower velocity inputs in general. City streets produced the most steering inputs above threshold, and the fewest below threshold. Also, city streets produced higher accelerator velocity inputs than the other two road types, and more gross accelerator position changes than the other two road types. The two-lane highway, contrary to hypotheses, produced moderate results, between the other two road types for all of these variables. This may be due to the actual roads included in the routes; most of these were fairly high quality, well travelled two-lane highways. It is expected that if other two-lane highways, with more curves and in greater states of disrepair, were used, then the results may have been less favorable.

Only RMS steering velocity showed significance for the method by road type interaction. An inspection of the means in Figure 25 shows that the main locus of the interaction was the difference manifested in this variable in city street driving. In this condition the memorized route method produced the highest mean RMS steering velocity; the paper map produced mean values which were considerably lower, and the navigator produced mean values which were much lower still than those produced by the paper map.

This helps to explain the specific reason for the significant main effect of navigation method on this variable.

An inspection of the means in Figure 23, and Figure 24 shows that the locus of the gender by road type interaction to be primarily due to differences in driving behavior on two-lane highways. For example, with regard to braking behavior, males and females produced similar performance except on the the two-lane highway condition; under these conditions, males activated the brake considerably more than females. Again with regard to the variable RMS accelerator velocity, the largest difference between the genders was on two-lane highways. Males produced lower mean RMS accelerator velocity scores than females; this considered together with the results regarding braking behavior may explain what was happening on the two-lane highways. It is possible that the males were less conservative than the females in adjusting the accelerator pedal to accommodate the increase in curves and hills associated with the two-lane highways. If this were the case, the logical result would be increased braking to maintain control of the vehicle (i.e., the females modulated the accelerator to a greater extent than the males as a means of keeping the vehicle under control).

Traffic density

Traffic density did not have a major influence on the results of this study, yet this factor was significant for the variables EYEDRIVE and EYEMAP/NAV. This showed that the amount of visual attention allotted to the driving task itself increased somewhat in the presence of heavier traffic (i.e., EYEDRIVE increased and EYEMAP/NAV decreased in the presence of heavier traffic). This points to the fact that when faced with a more taxing driving situation, the driver tends to focus more on the driving task, leaving less spare visual capacity (i.e., capacity which could be devoted to navigation behavior).

The significant traffic density by driving experience interaction supports the notion that spare visual capacity is reduced under stressful driving conditions. Individuals with low driving experience visually attended to the driving task virtually the same in conditions of low or moderate traffic. However, high driving expererience subjects considerably increased the amount of visual attention devoted to the driving task in heavier traffic, approximately to the same level as the less experienced drivers. It is possible that the high experience drivers felt less of a need to devote attention to the driving task in low traffic, because of actual or perceived driving skills.

The traffic density by navigation method was also found to be significant with regard to the variable, DRIVELINK. Drivelink indicates the strength of the links between glance categories strictly concerned with the driving of the vehicle. An examination of the means on these two factors (Figure 11) shows that the strength of the interaction is largely dependent upon the decrease in DRIVELINK demonstrated by drivers in the memorized route condition in high traffic compared to the low traffic density mean.

Traffic density was determined, in this study, strictly by when the experimental run took place (i.e., in relation to the morning or afternoon rush hours). No attempt was made to count vehicles or otherwise empirically determine traffic density during an experimental run. Because of this, there was fairly high variability in actual traffic density during most runs; this could have contributed to obfuscating other important effects of actual traffic density.

Subject Factors

Spatial ability

The main effect of spatial ability was significant on certain glance probability parameters. These measures indicated that subjects in the high spatial ability group looked at the map and the navigator less than their counterparts in the low spatial ability group. This shows that there is a relationship between spatial ability and navigation performance as would be expected based on the link that has been shown to exist between spatial ability and map reading ability (Stasz, 1980; Stasz and Thorndyke, 1980). In spite of these findings, it must be remembered that the overall measures of navigation performance showed no differences with regard to spatial ability.

Age

Age did not have an effect on the measures of driving quality, nor on the measures of navigation performance in this study. On an anecdotal basis, older subjects seemed to be more cautious than the other subjects, and they seemed, in general, to be less willing to take risks in the use of either the paper map or the navigator. An examination of Figures 17 and 18 shows that the older subjects actually devoted less visual attention to the roadway(center) and more to the navigational devices than their younger counterparts. Although this result is counterintuitive with respect to their seemingly more conservative driving style, it is likely that this was a result of the older subjects feeling more comfortable in their role as navigator, since most had a wealth of experience in this role (i.e., with paper maps or other methods).

Also the self-paced nature of the experimental task in this study seemed to allow the older subjects to compensate for any perceptual or processing decrements which may have been present.

Gender

Gender, as expected, did not contribute to many significant results in the study. Males visually attended to the driving task less than females. This indicates that males, either due to real or perceived skills, were less conservative in driving behavior than females. This idea is in congruence with results discussed earlier in which it was indicated that males possibly demonstrated less conservative brake/accelerator behavior, especially on two-lane highways. Even so, the differences found in this study between males and females were slight.

Questionnaire

Both methods of navigation were perceived, based on average scale markings, as being easy to use, with the paper map receiving a slightly higher average rating. The single most critical behavior that must be learned if the navigator is to be successfully used for navigation is when to zoom in and out, and which scale level to select at any given point in the route. The questionnaire provided an opportunity to rate the ease/difficuly of maintaining the correct zoom level in use of the navigator. The average rating for this item was somewhat less than for the overall ease/difficulty rating for the navigator.

This may give insight into why the navigator was preferred to the paper map in general, even though it provided no increment in navigational effectiveness. Subjects seemed to be genuinely intrigued by the new technology represented by the navigator, and so it was preferred to the old, standard technology of the paper map. However, when a specific critical issue was raised, the ease/difficulty in maintaining the correct zoom level, then the praise became somewhat more subdued.

Although the factor of age showed little with regard to the objective variables, it did reveal some interesting facts with regard to the questionnaire. The older subjects (50+) perceived using the map, the navigator, and maintaining the correct zoom level on the navigator to be easier than did their younger counterparts. This is consistent with the experimenters' opinion that the older group of subjects was more comfortable in the act of navigation than the younger group. Interestingly, the older group of subjects preferred the navigator to the paper map even more strongly than did the younger subjects. This was contrary to the original hypothesis, since it was expected that the greater experience of the younger subjects with computers (the younger subjects reported interacting with computers 11.17 hrs/wk compared to just 6.88 hrs/wk for the older subjects) would promote the opposite result.

With regard to the advantages of paper maps and the navigator which were selected by subjects, the results were as expected, and they agree, largely, with the objective results of the study. As a matter of interest, more than half of the subjects agreed that one advantage of paper maps was that they could be written upon; however, only one subject asked to write on the paper map. He did, and he ended up taking a major wrong turn, never coming close to the vicinity of the destination. Since the destination was already marked with a red arrow, it is likely that most subjects did not feel the need to put additional markings on the map. Of course, because writing on the maps was not suggested by the experimenters, subjects may have simply not realized that this was an option. It was decided not to suggest to subjects that they could write on the map so as to not influence the "natural" way in which they would normally use a map.

Finally, subjects were given open-ended opportunities to express any feelings that they had about the navigator and any changes that they would like to see incorporated in future design iterations. These comments were synthesized and included in the Recommendations section.

Summary

Navigation effectiveness and strategy

The paper map took longer to study at the beginning of a run than the navigator; this was its only demonstrated disadvantage. Even with this handicap, the total time taken (including the study time) was slightly less when using the paper map compared to the navigator. There were no differences in the directness or quality of routes selected when using either method to navigate. The key to understanding these results is in understanding the strategy adopted in the use of each method. The paper map was used to plan, essentially, the entire route from start to finish. After this initial study phase, the map was used only as an occasional reference. In contrast, the navigator could provide only general route information beyond approximately a one half mile radius of the current location of the vehicle. Effective use of the navigator could only be accomplished by continually glancing at the display to acquire important information as it was updated and presented. As a result, subjects spent more time during the run glancing at the navigator than at the paper map. The navigator significantly drew the subject's gaze away from the driving task relative to the norm established in the memorized route condition, as well as in comparison to the paper map.

These differences relate directly to the discussion of cognitive mapping presented earlier. It seems that the paper map aids in the representation of a cognitive map of an area (for any distance beyond one half mile) to a greater extent than does the navigator.

This concept can perhaps best be explained in terms of the differences between the two types of mental map representations referred to by Byrne (1979): the vector-map and the network-map. The vector-map deals with absolute spatial relations in terms of vectors; that is, the relationships between nodes are encoded in terms of fixed angles, distances, and directions among the nodes or locations. The network-map preserves what Byrne (1979, p.153) refers to as "topological connectedness" which deals with the order of key nodes and whether one node is connected to another by a roadway. With this type of representation, exact distances, locations, and angles are not important.

The difference between the two forms of mental map representation is related to the comparison of the navigator to the paper map. The navigator can provide mostly vector-map information for distances beyond one half mile; the display indicates current location of the vehicle and its directional relationship to North and the destination, and its distance to the destination. The paper map provides these bits of information only roughly and only implicitly, but it does provide a complete network-map for subjects to study and derive the information regarding topological connectedness so important for navigation.

There is also another, separate issue at work in the complete explication of the results. It has been argued that there are aspects of the navigator system which require that attention be continually directed to the device, and this notion is supported by the navigator owner's guide (Etak, 1985b) which states that the planning of the route should be done online, while driving toward the destination, not all at once at the starting point. The subjects tested in this study had never before encountered the navigator or any similar device. So, although they received fairly rigorous and extensive training to an explicit training criterion, these subjects must accurately be considered "practiced novices." This was likely instrumental in forging some of the key results of the study; it is very likely that the novelty of the navigator was also responsible for a portion of the time-sharing demands. That is, after weeks of use, it is likely that the navigator would no longer draw as heavily on visual attention.

Intrusion

The intrusion aspects of the navigator in regard to visual processes have already been addressed. Driving quality measures, though, did not show a clear performance oriented picture of how the increased visual time-sharing using the navigator affected driving performance. However, important measures such as lane exceedence and brake application did not change as a function of navigation method. Also, there were no accidents or near misses. This leads to the conclusion that the additional attention demanded by the navigator was drawn primarily from spare resources.

Subject factors

Results indicated that subjects with high spatial ability may be able to derive the necessary information from the navigator or the paper map in less time than those with low spatial ability. Males and females generally did not perform very differently, but males did seem to drive in a somewhat less conservative fashion than females.

Environmental factors

Driving quality measures indicated that city driving is more difficult than two or four-lane highway driving with regard to the frequency, magnitude, and speed of the various control inputs required. Despite the variability in traffic density during a run, this factor helped to show how spare visual capacity can be reduced when the demands of the driving task are increased.

Questionnaire

Subjects projected basically positive feelings about the paper map and the navigator; one surprising result was that the response of the older subjects was more positive than that of the younger ones in their preference for the navigator.

Conclusion

Thirty two practiced novices were used to evaluate the effectiveness and the efficiency of a moving-map navigational display relative to more conventional means of automobile navigation. Subjects liked and preferred the device, and it was as effective a navigational tool as a paper map.

A major problem uncovered in the examination of the device, though, was the drawing of the driver's visual attention from the driving task, greater than when using a paper map, and much greater than when a subject was navigating along a memorized route. It is felt that there were two main reasons for the increased attention: (1) the design of the device requires continual monitoring on the part of the driver for the device to be an effective navigation tool, and (2) the novelty of the device drew driver's spare visual attention, substantially beyond what more experienced subjects would likely exhibit.

The navigator is an effective navigation tool; its present configuration requires a great deal of attention, especially for a novice. A key direction for future research would be to examine the effects of intensive training, and prolonged practice and experience on the level of visual attention demanded by the navigator. It is also important that future considerations of the attentional demand associated with in-dash devices attempt to empirically determine the extent to which the attention demanded is drawn from spare resources, and the effect that this may ultimately have on the safety of the vehicle equipped with such devices.

RECOMMENDATIONS

Navigator Improvements

Several design enhancements can be recommended for future navigation devices. These recommendations are based on the empirical results of the study, subject comments, and the general experiences of the experimenters.

Display detail

One key recommendation is to allow the device to show greater detail at the higher scale levels, on a per request basis (i.e., a button press). This could substantially alleviate the problem whereby subjects cannot plan detailed routes, when the destination is farther than one half mile from the current location of the vehicle. This would also help to eliminate the problem of the hidden dead end. Recall that this is the problem that exists when one scale level suggests that a particular direction be selected (i.e., based on the destination arrow), but the next lower scale level does not show enough area to reveal the fact that the direction indicated is a dead end. Also recall that each experimental route was carefully selected such that no hidden dead ends would be encountered in the present study.

The obvious problem with this recommendation is the increase in display clutter which would result; the navigator, with its many available scale levels, was designed to avoid display clutter. Still, measures could be implemented toward a compromise. One measure could be to use a larger screen. The model of the navigator tested in this study had a four inch diagonal screen, but a larger model might also be made available. The extra area provided on the larger screen may reduce the clutter of a more detailed display. Also, color coding could be used to indicate which are the roadways that normally appear at each scale level, and which are the temporarily displayed roadways used to provide additional detail. Even with the additional clutter, adding detail on a temporary, per request basis may prove to be an attractive design enhancement.

Zoom flexibility

Another design change which might be implemented with current software technology is to increase the zoom flexibility by allowing the locus of the zoom to be at a point other than the current location of the vehicle. For example, if a user could zoom in and out with the locus of the display being the selected destination, then this would be a great aid in the long distance planning of routes.

There exists in the present navigator a pan function which subjects were not trained or allowed to use. This function is similar in concept to the flexible zoom, but is more limited. The pan function allows the user to view the map in the area surrounding the presently displayed area. There is a limit, though, as to how far one can pan, and more importantly, the zoom function is locked out when panning.

Other modifications

Other simple changes which might be helpful include the following. An LED or a lighted button could be used to show which scale level is currently on the screen. This would help to reduce display clutter, since this information could then be removed from the display. More importantly it would eliminate possible confusion between the scale indicator and the distance to the destination (both located at the upper center portion of the display).

It is interesting to note that the scale level is currently given in whole numbers and fractions--no decimals are used. The distance to the destination, on the other hand, is displayed in decimal form (when the destination is within ten miles of the current location). This is done, presumably, to avoid confusing the distance to the destination with the current scale level. However, the relationship between these values is important, since a general rule of thumb is that one should usually be on a scale which is close to the distance to the destination to maximize the amount of detail shown, while at the same time keeping the destination star on the screen. Therefore, a conversion of one of the values must be made; this can be somewhat confusing, especially for distances and scale levels below 1. A possible solution to this dilemma would be to mark the scale level buttons in decimal form, and to use a lighted button to indicate which scale is currently in use. This would remove the scale level information from the screen, make the current scale level more obvious (e.g., the lighted button may be at the top or bottom of the column of buttons), reduce display clutter, eliminate the confusion of these two important pieces of information, and eliminate the need for a somewhat complex conversion to relate the two numbers.

Information regarding existence of interstate exchanges could be added, as could information pertaining to landmarks. Of course, adding information to the display must always be balanced against the concern of display clutter.

One feature which may be very helpful, yet would increase clutter only slightly is the addition of a mark to indicate cross streets on roads on scale levels where the cross streets do not normally appear. This would allow the user to count the number of streets between the current location and a desired turnoff, and it would at least hint at what useful information may be presented at a lower scale level.

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Appendix A. INTRODUCTION AND INFORMED CONSENT

Instructions Given to Subject Prior to Obtaining Informed Consent

Introduction to the Navigation Study

The purpose of the study is to evaluate driver performance using various methods of navigation. This study is being conducted by the Human Factors Laboratory, Department of Industrial Engineering and Operations Research, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061, telephone number: (703) 961-7962. The research team consists of Jon Antin, Tom Dingus, and Melissa Hulse, who are graduate students in Industrial Engineering and Operations Research under the direction of Dr. Walter W. Wierwille, principal investigator and Professor of Industrial Engineering and Operations Research.

In the study you will at times be asked to navigate unfamiliar routes in the local area; at other times you will be asked to perform various tasks commonly done while driving. Two trained experimenters will ride in the car with you through the experiment to participate in the data gathering process and to help ensure the safe operation of the experimental vehicle. It is your responsibility as the driver to obey all traffic regulations and to maintain safe operation of the vehicle at all times. You will, at all times, be required to have the lap and shoulder restraints securely fastened.

The experimental vehicle, a late model American car will be outfitted with instrumentation designed to gather relevant data.

The vehicle will be outfitted with devices designed to monitor various relevant aspects of driver behavior. These measurement devices do not require that your attention be diverted from the driving task. All equipment will be placed in the vehicle and secured such that it will not present a hazard. Also, a fire extinguisher, a first-aid kit, and a CB radio will be carried in the vehicle at all times, in case an emergency occurs.

The study basically consists of three sessions:

Session I:

This will be a practice session in which you will learn how to use the ETAK Navigator, an in-car moving-map navigation display. You will also be familiarized with the vehicle's regular dash instrumentation. While the vehicle is parked, you will be shown how the navigator works and you will practice with it. Similarly, you will practice with the dash instrumentation. Thereafter, you will drive with the navigator and continue to learn how to use it and the other dash instrumentation. The driving will continue until you are thoroughly familiar with the use of the navigation system and the dash instrumentation.

Session II:

This session will involve the performance of instructed tasks and the gathering of information from in-dash instruments while driving. If you feel at any time that the demands of the driving task are too great, all experimental tasks should be delayed until the driving task is firmly under control.

Upon completion of the sessions, you will be paid at the rate of $5.00/hr. If during the study you feel that you cannot continue for any reason, you have the right to terminate your participation; you will be paid for your participation up to that time. This includes the right to withdraw after having read and signed the attached informed consent form.

If you have any questions about the experiment or your rights as a participant after reading the attached informed consent form, please do not hesitate to ask. We will answer your questions as openly and honestly as possible; however, answers to some of your questions may be delayed until you have completed the experimental sessions in order to avoid biasing the outcome of the study. We ask that you please not discuss the details of this experiment with anyone, especially potential subjects, since prior knowledge of seemingly incidental facts could seriously affect the outcome of the study. It is expected that all data will have been gathered by June 15, 1986; you may feel free to discuss the study with anyone after that date.

It is possible that at times the tasks may seem difficult, and you may feel stressed and frustrated. Your performance and feelings reflect the difficulty of the task, not your personal abilities and talents. Further, your data will be treated with anonymity; that is, shortly after completion of your experimental sessions, your data will no longer be associated with your name.

There are some risks inherent in this study. They are outlined in the following informed consent form.

Session III:

This session will involve the use of three methods of navigation to drive from given starting points, along unfamiliar routes, to given destinations. The three methods will be: 1) memorized route in which case you will drive along a given route until a set of criterion of performance is achieved, 2) paper map in which case you will use a standard paper map of the area to navigate the unfamiliar route, and 3) the ETAK Navigator in which case you will use the in-dash navigational display to navigate the unfamiliar route.

Although it is important to navigate the routes as quickly as possible, it is also important to minimize errors (e.g., wrong or missed turned). Therefore, if necessary, you may stop the vehicle at any safe and legal place to more accurately navigate the route. Routes with heavy traffic will be avoided.

PARTICIPANT'S INFORMED CONSENT

1. You are being asked to volunteer to be a subject in a research project whose purpose and description are contained in the document "Introduction to the Navigation Study," which you have already read.

2. There are some risks and discomforts to which you expose yourself in volunteering for this research.

   The risks are:

   a. The risk of an accident normally associated with driving an automobile in light or moderate traffic,

   b. The slight additional risk of an accident that might possibly occur while reading the ETAK display,

   c. The slight additional risk of an accident that might possibly occur as a result of listening to instructions from one of the experimenters.

   The following precautions will be taken during your driving:

   a. The experimenters will monitor your driving, and will ask you to stop if they feel the risks are too great to continue. However, as long as you are driving the research vehicle, it remains your responsibility to drive in a safe, legal manner.

   b. You will be required to wear the lap and shoulder belt restraint system anytime the car is on the road.

   c. The vehicle will be equipped with a fire extinguisher, first-aid kit, and a CB radio.

   d. The front seat experimenter will have an override brake pedal.

   e. If an accident does occur, the experimenters will arrange medical transportation to a nearby hospital emergency room. You will be required to undergo examination by medical personnel in the emergency room.

The discomforts in this experiment are:

a. The length of the experiment, which could be as much as six hours. (There will be rest breaks, however.)

3. The data gathered in this experiment will be treated with anonymity. Shortly after you have participated, your name will be separated from your data.

4. While there are no direct benefits to you from this research (other than payment), you may find the tasks interesting, particularly while using the ETAK system.

   Your participation, along with that of other volunteers, should make it possible to improve in-car navigation displays before they become widely available to the public.

5. You should not volunteer for participation in this research if you are under 18 years old, or if you do not have a valid driver's license, or if you are not in good health, or if you are pregnant, or if you have taken any drug, alcoholic beverage, or medication within the last 24 hours. It is your responsibility to inform the experimenters of any additional condition which might interfere with your ability to drive. Such conditions would include inadequate sleep, hunger, hangover, headache, cold symptoms, depression, allergies, premenstrual syndrome, emotional upset, visual impairment, seizures (fits), nerve or muscle disease, or other similar conditions.

6. You should know that the principal investigator of the research project and his associates will answer any questions that you may have about this project, and you should not sign this consent form until you are satisfied that you understand all of the previous descriptions and conditions.

   You should further be aware that you may contact Mr. Charles D. Waring, Chairman of the University's Institution Review Board, if you have questions or concerns about this experiment. His phone number is (703) 961-5284.

7. You should know that at any time you are free to withdraw from participation in this research program without penalty.

   You will be paid at a rate of $5.00 per hour for the time you actually spend. Payment will be made shortly after you have finished your participation.

8. Signature of the volunteer and date:

I have read and understand the scope of this research project and I have no other questions. I hereby give my consent to participate, but I understand that I may stop participation if I choose to do so.

Signature ______________________________

Date ______________________________

9. Signature of a member of the research team and date:

Signature ______________________________

Date ______________________________

10. Signature of witness, not a member of research team and date:

Signature ______________________________

Date ______________________________

If you would like a written summary of the results of this study, please print your address 3 months from this date:

____

____

____

____

Appendix B. QUESTIONNAIRE

SUBJECT NO. ______________

NAVIGATION EXPERIMENT QUESTIONNAIRE

We ask that you answer the following questions as thoroughly and as honestly as you can. If you feel that you cannot answer a question for any reason, simply leave it blank.

I. General Information

1. ______ Gender (M or F)

2. ______ Age

3. ______ How many years have you been driving?

4. Estimate the number of miles you drive each year.

☐ 0-2,000 miles	☐ 10,000-14,000 miles
☐ 2,000-6,000 miles	☐ 14,000-20,000 miles
☐ 6,000-10,000 miles	☐ 20,000 or more miles

(Place a check in the appropriate box)

5. Have you ever used a map to navigate in an automobile?

☐ Yes

☐ No

6. Have you ever used any device or aid other than a map or compass to navigate in an automobile?

☐ Yes

☐ No

(Place a check in the appropriate box)

If you checked yes, briefly describe the navigational aids, or device(s)

____

____

____

7. Estimate the number of times per month you drive to a destination whose location is unknown.

______ times/mo.

8. Estimate the number of hours you spend per week interacting directly with computers.

______ hrs/wk

9. Have you ever participated as a subject in any previous scientific research or experiment?

☐ Yes

☐ No

(Place a check in the appropriate box)

HEALTH, MEDICATION, AND DRUG QUESTIONNAIRE

1. Are you in good general health? Yes No

   If no, list any health-related conditions you are experiencing or have experienced in recent past.

   ____

   ____

   ____

2. Have you, in the last 24 hours, experienced any of the following conditions?

Inadequate sleep	Yes	No
Unusual hunger	Yes	No
Hangover	Yes	No
Headache	Yes	No
Cold symptoms	Yes	No
Depression	Yes	No
Allergies	Yes	No
Pre-menstrual syndrome	Yes	No
Emotional upset	Yes	No

3. Do you have a history of any of the following?

Visual Impairment Yes No

(If yes, please describe.)__________________________

____

____

Hearing Impairment Yes No

(If yes, please describe.)__________________________

____

____

Seizures or other lapses of consciousness Yes No

(If yes, please describe.)__________________________

____

____

Any disorders similar to
the previously mentioned
ones or that would
impair your driving
ability Yes No

(If yes, please describe.)________________________________

4. List any prescription or non-prescription drugs you are currently taking or have taken in the last 24 hours.

5. List the approximate amount of alcohol (beer, wine, fortified wine, or liquor) you have consumed in the last 24 hours.

6. Are you taking any drugs of any kind other than those listed in 4 or 5 above? Yes No

7. If you are female, are you pregnant? Yes No

____
Signature

____
Witness

____
Date

III. EXPERIMENT INFORMATION

1. How easy or difficult was the ETAK to use in finding the destination?

-5	-4	-3	-2	-1	0	1	2	3	4	5
very difficult					moderate					very easy

(Mark at the appropriate place on the line)

2. How easy or difficult was the paper map to use in finding the destination?

-5	-4	-3	-2	-1	0	1	2	3	4	5
very difficult					moderate					very easy

(Mark at the appropriate place on the line)

3. How easy or difficult was it to maintain the correct zoom level in use of the ETAK?

-5	-4	-3	-2	-1	0	1	2	3	4	5
very difficult					moderate					very easy

(Mark at the appropriate place on the line)

4. Were there any features on or aspects of the ETAK that you would change, alter, add, or delete?

   ☐ yes

   ☐ no

   (Place a check in the appropriate box)

   If you checked yes, please elaborate.

   ____
   ____
   ____
   ____
   ____
   ____
   ____
   ____
   ____
   ____

5. Which method of navigation did you prefer using?

   Paper map same ETAK

   5 4 3 2 1 0 1 2 3 4 5

   (Mark at the appropriate place on the line; the stronger you feel, the higher the number you should mark.)

6. With regard to automobile navigation, check *any* of the following that you feel are worthwhile advantages of paper maps compared to the ETAK. *Only* check those items that you feel are *true and advantageous*.

   ☐ Paper maps are more conventional; people are simply more used to using them than the ETAK.

   ☐ Paper maps show the entire area at once (i.e., there is no zoom-in/zoom-out with paper maps).

   ☐ Paper maps do not change headings; North is always up on a paper map.

☐ Paper maps are easier to see and read than the ETAK.

☐ Paper maps differentiate among the various types of roadway better than the ETAK.

☐ Paper maps are less distracting than the ETAK.

☐ Paper maps show greater detail than the ETAK.

☐ Paper maps can be written upon.

☐ Paper maps are simpler to use than the ETAK.

☐ Other, please explain.

7. With regard to automobile navigation, check <u>any</u> of the following that you feel are worthwhile advantages of the ETAK compared to paper maps. <u>Only</u> check those items that you feel are <u>true and advantageous</u>.

- ☐ The ETAK shows the location of the vehicle on the map at all times.
- ☐ The ETAK shows only relevant information (i.e., level of detail is determined by the chosen zoom level).
- ☐ The ETAK continually re-orients the map such that your heading is always up on the display.
- ☐ The ETAK requires no folding, holding, or unfolding as does a paper map.
- ☐ The ETAK is placed such that it can be conveniently used while driving.
- ☐ The ETAK shows the vehicle's distance to the destination at all times.
- ☐ The ETAK indicates the direction from the vehicle to the destination at all times.
- ☐ The ETAK is less distracting than paper maps.
- ☐ The ETAK is simpler to use than paper maps.
- ☐ Other, please explain.

____

____

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____

Appendix C. DESCRIPTION OF THE ROUTES AND PAPER MAPS USED FOR THE STUDY

Experimental Routes

The three experimental routes were selected such that there would be a destination in each of three neighboring towns in Virginia: Blacksburg, Christiansburg, and Radford. The use of a different town for each of the routes insured that navigation along any one of the routes would not help to familiarize the subject with either of the other two routes.

Each route was designed to sample each of three different road types: four-lane highway, two-lane highway, and city or residential streets. Optimal navigation behavior resulted in the traversing of each road type on each route;

however, since subjects were free to navigate freely from a starting point to a destination, the actual route chosen by a given subject may not have sampled each road type on each route.

The starting point of each route was on a two or four-lane highway outside of one of the three three towns; each destination was an intersection of two streets in a residential neighborhood. Each route was 3.0 + or - 0.5mi in length, and was designed so that an experienced driver could navigate the route in 10 to 12 min. In other words, driving times (for experienced drivers) were matched for the three routes--not distance. Obviously, driving time also obviously depends upon traffic lights and conditions.

The total number of stop lights, stop signs, yield signs or lights, left turns, right turns, and approximate mileage are shown in Table 19.

Paper Maps

The maps used were standard black and white street maps which included all highways and streets needed to navigate from the starting point to the destination; that is, all streets were shown on the map. Each of the standard maps was slightly altered with hand-drawn extensions so that the subject could follow the entire route from the starting point to the destination which were marked with a green S and a red star, respectively. A reduced size sample of the type of map used is shown in Figure 6.

Table 19. Detailed Route Information

	INTO BLACKSBURG	INTO CHRISTIANSBURG	INTO RADFORD
STOP LIGHTS	4	4	5
STOP SIGNS	2	1	4
YIELD SIGN/LIGHTS	1	0	1
RIGHT TURNS	5	3	3
LEFT TURNS	2	1	4
TOTAL MILES	2.5	3.5	3.0
DESTINATION INTERSECTION	CEDERVIEW & LANDSDOWNE	TURPIN & RIDGE	FOURTEENTH & FOUNDARY

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