EFFECTS OF VARIATIONS IN DRIVING TASK ATTENTIONAL DEMAND ON IN-CAR NAVIGATION SYSTEM USAGE

by

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(ABSTRACT)

This research was conducted to assess whether drivers, while navigating using an Etak automobile moving-map navigation system, could adapt when necessary to situations where higher levels of visual attentional demand associated with driving occur.

Two studies were performed to answer this question. The first dealt with changes in anticipated attentional demand. These changes were of the type that the driver could observe ahead of time. The attentional demand levels (low, medium, and high) were based on subjective and objective ratings of roadway segments which the drivers navigated. The second study assessed changes in unanticipated visual attentional demand. The demand levels were based on the type of interaction or monitoring required of other vehicles by drivers. The levels were light traffic, heavy traffic, and incident.

Twenty-four subjects participated in this research. Twelve males and 12 females were divided evenly into three age groups (18 to 30, 31 to 44, and 45 to 65). They were unfamiliar with the destinations to which they drove. Data

were collected on eye glance duration and glance patterns.

The overall results for both studies showed that drivers do in fact adapt to some degree to increases in attentional demand. Generally speaking, as attentional demand levels increased, drivers adapted by increasing the proportion of visual time spent viewing the forward roadway and decreasing the proportion of visual time spent viewing the Etak.

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INTRODUCTION

Since automobiles were first introduced into the marketplace they have had some sort of visual display system incorporated into the dashboard. Due to the available technology, the amount of information presented to the driver was usually limited to vehicle road speed, fuel level, and engine (coolant) temperatures (Fowkes, 1984). As technology has progressed, so have the methods and placement of vehicle controls and displays.

In today's automobiles, not only are drivers provided with essential information concerning the driving task, such as speed and fuel level, but they are also provided with other information in an effort to make driving easier, more comfortable, and presumably more enjoyable. Examples of the latter include digital speedometers; heating, ventilating, and air conditioning control centers; and trip monitoring information systems. The change taking place is mainly due to availability of electronics and, more recently, microprocessors and memory devices (Yun, 1985).

With the increase in options available to the driver, studies have been conducted regarding the effectiveness and efficiency of different display and control configurations. One of the more popular trends in automobile displays seems to be the use of digital displays to replace analog displays. Digital displays, as reported by Lopez (1982), are often better in reliability, performance, and appearance when compared to analog displays.

Advances in technology make it important to consider what a driver's capabilities are in obtaining information from displays and in properly using controls. Perel (1974) suggested that the number of direct looks to controls within finger-tip reach (within 18 cm of an operator's hand position on the wheel) may be fewer than when the controls are located on an instrument panel. Mourant, Herman, and Moussa-Hamouda (1980) compared different types of stalk control configurations and panel-mounted control configurations. Their findings showed that the farther a driver's hand had to travel to operate a control, the more looks the driver made to that control. Panel-mounted controls also required more direct looks than did stalk control devices. And finally, Mourant et al. (1908) found that the number of switches located on the different stalk configurations may be related to the number of direct looks.

Another study concerning control/display placement was conducted by Monty (1984). He compared a dashboard cathode-ray tube (CRT)/touch entry device (TED) to a more conventional control/display layout. The CRT/TED control/display device performed climate control, radio, trip monitor, and engine monitoring functions. The results showed that the CRT/TED device required more glances to operate a control and produced longer task completion times than the conventional control/display layout. He also found that the quality of driving, measured by brake usage, lane deviation, and speed, was degraded somewhat when using the CRT/TED device and that attentional demand increased in comparison to the conventional control/display.

One of the more recent electronic automobile devices helps a driver navigate. Experimentation with locating moving automobiles on maps started in the early 1970s. One method used terrestrial magnetism to track a car using radio transmissions on data between the automobile and a ground site. Usually the car was linked to a host computer which was located at the ground site. The Motorola Corporation, which experimented with a gyroscope to determine vehicle direction, was one company that explored the use of navigation systems (Totani, Kato, and Muramoto, 1983).

At the 1981 Tokyo Motor Show various Japanese companies, including Toyota, Nissan, and Honda, introduced CRTs which were capable of displaying maps and the location of the vehicles on them. Through the use of cassette tapes and floppy disk storage, parts of the electronically recorded maps could be displayed on the screen. Totani et al. (1983) also reported that these systems did not require host computers to be located at a ground site, but actually had on-board computers.

Honda's navigational device incorporates an

Electrogyrocater,an inertial navigation system which operates on terrestrial magnetism. This system uses gas-rate gyro and distance sensors. A gas-type gyro sensor provides information as to the direction the car is moving. It has two hot wires which detect changes in the helium gas flow. This flow changes according to whether the car is moving straight or turning. Information from these sensors is processed by a microcomputer, which displays the data overlaid on a CRT screen map. The map displays an entire city or region of Japan. This system can give the driver information as to the car's present location, direction, and route (Jurgen, 1982; Tagami, Takahashi, and Takahashi, 1983).

The Etak Navigator

Etak, Inc., has introduced a navigation system, the Etak Navigator (navigator), that is currently available for commercial installation. The only known operational system that is in production, this system displays a map on a CRT screen (not an overlay) and the system allows the driver to program an exact destination which will simultaneously appear on the screen. The system has five parts. The first is a display screen mounted on the dashboard that measures 7.5 cm high and 10.1 cm wide; map information which is displayed on the screen is stored on special cassette tapes. The tape drive which reads the tapes is usually located on the floor under the dashboard. The third part of this system is the computer, which is located in the trunk of the car or under a seat. The navigator also uses an electronic compass, as a secondary device, mounted under the roof or on the rear window. The fifth component of the navigator is a set of wheel sensors. Magnetic tape is positioned on the inside of the two wheel rims. A sensor located next to each magnetic tape provides a signal which allows measurement of distances (Etak, 1985b).

The navigator system uses augmented dead reckoning to keep track of the direction and distance the car has travelled. Dead reckoning works by processing the information sent from the compass sensor and the wheel sensors reporting the current location of the car. One problem with dead reckoning is that the calculated position of the car could eventually deviate from the actual position of the car due to accumulated error. Augmented dead reckoning uses the same principles of operation as dead reckoning but with one additional feature. As the vehicle is traveling, the navigator adjusts the position of the vehicle based on stored map information. For example, a driver may turn a corner and the cursor representing the driver's current location on the screen might show the car turning just before the actual road, where no road is present. In a few seconds the navigator corrects itself and repositions the cursor in the road (Etak, 1985b).

Two of many interesting features of the navigator are its zoom-in and zoom-out functions. If the driver is looking at an area of the map and wishes to see more detail, the driver can push the zoom-in button. To see less detail and a larger area, the zoom-out button can be pushed (Etak, 1985a).

VIRGINIA TECH STUDIES EVALUATING IN-CAR NAVIGATION

Extensive research has been conducted at Virginia Tech on the Etak in-car navigator (Antin, Dingus, Hulse, and Wierwille, 1986; Dingus, Antin, Hulse, and Wierwille, 1986). Dingus et al. (1986) investigated the attentional demands of drivers while performing tasks associated with the navigator and conventional controls/displays. The objective was to compare the attentional demand requirements of the driver when performing tasks associated with the navigator with the demand requirements when using conventional controls and displays found in a late model American car.

Performance and behavioral measures were obtained from 32 subjects of both genders, with high (more than 10,000 miles per year) and low (between 2,000 and 10,000 miles per year) driving experience, and ages ranging from 18 to 73 years of age. Some of the measures included lane maintenance, steering wheel movements, accelerator movements, and brake activation measures.

The goal of the experiment was to determine which tasks required high attentional demand. Analyses were also conducted to provide groupings of tasks which required roughly the same amount of attentional demand.

Based on the total required display glance time, the three tasks which required the most time were navigator tasks in which the driver had to extract information from the display. However, it was found that there were large differences in attentional demand requirements when the information was immediately available and when the driver was required to zoom in or zoom out. When the information was immediately available, less time was required to complete the task. The authors also found that many of the navigator tasks had high average single glance times of 1.2 seconds or more. These times were longer than those required for conventional tasks. Dingus et al. (1986) concluded that information displayed on the navigator was more complex than the information obtained from the conventional tasks.

The tasks that required the highest attentional demand were adjust the side power mirror, tune the radio, activate the cruise control, and the three navigator tasks previously mentioned. While age and road type did show significant differences among the dependent measures (which will be discussed later), gender did not.

The second study (Antin et al., 1986) conducted at Virginia Tech had two objectives. The first was to evaluate the relative efficiency and effectiveness of three methods of navigation. The three methods were a memorized route (which served as a baseline condition), a conventional paper map, and a moving-map display (the navigator). The second objective was to assess the driver's navigational strategies and how the different types of navigational methods affected these strategies.

In the Dingus et al. (1986) study, a subject was directed along a preselected route by the experimenter. For this second experiment, (Antin et al., 1986) a destination was delineated and the subject was asked to navigate to it. Each route sampled two-lane, four-lane, and city streets.

The results showed that during the beginning of a run, before the car was in drive, subjects studied the paper map longer than the navigator. This time difference was made up during the run, however. The experimenters pointed out that with a paper map the subject can plan an entire route at the beginning of the run. With the navigator, however, only a small portion of the map around the current location of the vehicle can be shown in great detail, so the driver cannot plan an entire route at the beginning. Instead, the driver has to consult the moving-map display throughout the run to navigate to the destination. When comparing the amount of time spent focusing upon the driving task while using the navigator to the norm established during the memorized route condition, there was a significant difference. There was also a significant difference between the paper map and navigator. No significant differences were found in the directness or quality of routes selected.

Antin et al. (1986) pointed out that the subjects used in this experiment were "practiced novices". The subjects were trained for approximately two hours on the use of the navigator. Because of this short training period, it is likely that some portion of glance time spent on the navigator may have been due to its novelty.

The authors reported changes in the scan pattern link value diagrams when using the navigator. They also reported that there was only slight intrusion on the driving task when using the navigator. There were no accidents or near misses. It was suggested that the additional time-sharing required when using the navigator was drawn mainly from spare resources.

ATTENTIONAL DEMAND

Anticipated and Unanticipated Attentional Demand

When discussing attentional demand, one must consider unanticipated as well as anticipated attentional demand. Unanticipated attentional demand occurs largely without advance indication, such as when a car pulls out into the street directly in front of the driver. The driver then has little or no time to formulate an avoidance strategy. Anticipated attentional demand allows that driver to plan ahead of time how to avoid an object or maneuver through a certain traffic situation. When driving on a two-lane road, if the driver sees a one-lane bridge farther down the road, then time is available to plan how to maneuver across the bridge. The driver may want to change the radio station, but realizes that attentional demand is required to maneuver across the bridge. Therefore, the driver waits until the bridge is crossed to change the station. This example represents anticipated attentional demand in that the driver has time to decide where attention should be allocated before the actual high demand situation is present.

Eye Scanning Studies

Rockwell (1972) states that over 90 percent of the information input to the driver comes from vision. Accordingly, one way to determine different levels of attentional demand is to examine eye scanning behaviors of people while driving. There are many ways to obtain eye movement data, as discussed by Young and Sheena (1973).

Mourant and Rockwell (1970) conducted a study to learn what effects route familiarity would have on subjects' search and scan patterns, to discover which visual cues drivers used while driving, and to find differences between open road driving and car following. The findings showed that as drivers became more familiar with a route the visual sampling of the roadway was confined to a smaller area. It was also found that peripheral vision plays a key role in monitoring other vehicles and road markers. When subjects were instructed to follow a lead car and maintain a certain distance from it, a slower visual sampling rate resulted. The authors suggest that this may be due to the drivers' having to decide if they were keeping the correct distance from the lead car and adjusting the accelerator appropriately to maintain this distance.

Alcohol has an effect on eye fixations in that alcohol increases the mean duration time of eye fixations (Mortimer and Jorgeson, 1972). Mortimer and Jorgeson (1972) found that there were no significant eye fixation glance time effects due to alcohol between the 0.0% and 0.05% blood alcohol content (BAC) levels, although there were significant effects between 0.0% and 0.10%, and between 0.05% and 0.10% BAC levels. The authors point out that as a result of an increase in glance time while under the influence of alcohol, drivers may not be able to gather as much information as they would under sober conditions. For example, a driver has a certain amount of time to gather information from the dashboard instrumentation. Under sober conditions, the driver may gather all the information necessary. Under the influence of alcohol, however, the driver may need more time to process the information from the instrumentation and may not gather as much information as under sober conditions.

Driving Task Studies

Bhise, Forbes, and Farber (1986) studied how drivers use various controls and displays in a vehicle and their eye scanning behavior while doing so. The results indicated that for a complex task, i.e., more that one glance with a glance lasting longer than 1.0 second, drivers time-shared visually between the roadway and the display/control task. Bhise et al. (1986) also found that when a control was near the steering wheel the probability of a look was between 0.03 and 0.14, while at a control panel the probability of a look was between 0.35 and 0.72. Similar results were reported by Mourant et al. (1980) as discussed earlier.

Experiments have been conducted using a vision interruption apparatus (VIA) developed by Senders to test the attentional demand of drivers under different conditions (Farber and Gallagher, 1972; Senders, Kristofferson, Levison, Dietrick, and Ward, 1966). Research conducted by Senders et al. (1966) found that the level of attentional demand is dependent on the difficulty or complexity of the driving task.

The purpose of the Farber and Gallagher (1972) study was to test attentional demand during degraded visibility conditions with the use of different levels of filtered goggles. The authors point out that various subsidiary tasks have been used to assess spare capacity and attentional demand, but that this method has not been very successful. Their research required drivers to wear different optical density goggles while they had to maneuver through a slalom course at speeds of 30 and 45 mph. Results indicated that attentional demand was increased with denser goggles and higher speeds. They concluded that "visual degradation increased the difficulty of the vehicular control task, but that the more skilled drivers were less affected" (Farber and Gallagher, 1972, p.3).

Environmental Factors

A variety of environmental factors has been found to impact driver performance. They include road type, road curvature, and traffic density.

Road type. Several studies have indicated the effect of road type on driver performance. Monty (1984) obtained results which indicated that there were major differences in driving performance, such as lane keeping, when comparing state roads to four-lane divided highways and city streets. Antin et al. (1986) found that four-lane driving required fewer and smoother control inputs than city streets and two-lane routes. The results also indicted that city streets proved to be the most difficult to negotiate when compared to the two other road types. In addition, Dingus et al. (1986) found that two-lane rural roadways required the most attentional demand, followed by city streets. Four-lane limited access roadways required the least attentional demand.

Straight and curved roadways. It has been shown by Senders, Kristofferson, Levison, Dietrick, and Ward (1967), as well as others, that the amount of attentional demand increases when driving on curved roads as opposed to straight roadways. Cohen and Studach (1977) state that when driving on a curved roadway, the driver must constantly process information about the roadway ahead. The driver must always pay attention to the roadway so that a plan can be formulated to negotiate the curve and try to anticipate what the road ahead may bring. Curved roadways consist of "non-redundant elements which produce a relatively high uncertainty about the part of driving to come" (Cohen and Studach, 1977, p. 684).

Cohen and Studach (1977) conducted a study to obtain any eye scanning pattern differences between right- and left-hand curved roadways. The overall results showed that there was a change in eye scanning behavior before entering a curve. When approaching a curve, the mean eye fixation duration decreases and the driver mainly focuses on the future driving path. Cohen and Studach (1977) found that the subjects tended to look toward the white stripes along the right side of the road and toward the middle, but rarely looked to the left side of the road when negotiating a right-hand turn. When driving through a left-hand turn, experienced drivers not only concentrated on the left-hand side and the middle of the road, but they looked at the right-hand side of the road as well.

The second part of Cohen and Studach's (1977) study addressed anticipatory responses, such as changes in visual search activity, that might occur before negotiating a curve to the right. They found that as subjects got closer to entering a curve, their mean eye fixation duration times decreased.

Mortimer and Jorgeson (1972) found that there was a difference in eye scanning behaviors when driving on straight roads as compared with curved roads. When the driver is driving on straight roadways, eye fixations are usually in a 10-deg diameter cone around the straight ahead position of the driver. When driving around left curves, however, the driver's fixations shift to the left and they shift to the right on right-hand curves.

There are different phases a driver goes through when negotiating a curve. First, the driver has a period of anticipating the curve. This phase carries over into the beginning of the actual start of the curve, at which time the driver begins the stationary curve phase. During this phase the driver performs steering-wheel correction movements to stay in the correct lane. The last phase begins when the steering-wheel is returned to a central position at the end of the curve (Godthelp, 1986).

Godthelp (1986) used visual occlusion goggles which could be switched from transparent mode to a translucent mode to test differences between driving accuracy on curved roads and accuracy from a previous study on straight roads. He found that there were larger steering inaccuracies for a preview curve entrance task (the subject could not plan to negotiate the entire curve ahead of time), as compared to a preprogrammed task which consisted of changing lanes on a straight road (the subjects could plan the task ahead of time). Thus, it could be said that negotiating curved roadways requires more attentional demand than straight roads.

Traffic density. Traffic density may play a part in the amount of attentional demand necessary to perform the driving task efficiently. Senders et al. (1966) report that if a driver must drive through an area which has a large number of cross streets and driveways, where the chance of interacting with other vehicles is high, more attention must be paid to the driving task. Thus, the number of looks to the roadway would increase, as opposed to an area with a low density of traffic and intersecting roadways. These results are also supported by Antin et al. (1986), who showed that drivers pay more attention to the driving task when confronted with heavy traffic conditions.

Studies have been conducted to address the effects of traffic density on the driving task by having drivers follow a lead car. When in heavy traffic, drivers put a greater distance between themselves and the lead car (Rockwell, 1972).

Dingus et al. (1986) noted that some driving performance measures did show significant difference between low and moderate traffic conditions. For example, under low traffic conditions subjects had a higher number of lane deviations than in moderate traffic conditions. The authors report that this is a result of the greater attentional demand required for driving in moderate traffic. Antin et al.(1986) also found that traffic density had some influence on drivers' scan patterns.

Subject Factors

Age. Rackoff (1975) conducted a study with young drivers (ranging from 21 to 29 years of age) and older drivers (ranging from 60 to 70 years of age) to determine what, if any, differences there were in visual search patterns and driving performance. For part of the study, the subjects were asked to keep their eyes closed as much as possible while driving on an expressway. The results showed that the older subjects kept their eyes open an average of three times longer than the younger subjects. Rackoff (1977) attributes this to the older subjects' need for longer time durations to acquire information. He also suggested that older subjects require a longer time duration to recognize cues that are essential to the driving task.

Monty (1984) reports that older subjects (ages ranging from 45 to 70 years of age) required a longer period of time to complete tasks than the younger subjects (ages ranging from 18 to 30). They also had more brake activations and lane deviations while performing these tasks. The older subjects required more glances per task than the younger subjects. Monty (1984) states that the older subjects had a more difficult time in reading the CRT/TED display than the younger subjects, which might explain the larger number of glances required to complete a task.

Gender. In general, major differences between males and females in driving performance do not occur. However, Monty (1984) did report that females tend to look at the roadway more than males when performing secondary tasks, and females looked at the display/control panel more times than the male subjects did. Antin et al. (1986) reported that females paid more visual attention to the driving task than males.

RESEARCH OBJECTIVES

As discussed previously, the Dingus et al. (1986) and Antin et al. (1986) studies indicated that changes take place in the driver's visual scan patterns when using the navigator. Dingus et al. (1986) found that performing certain navigator tasks required higher visual attentional demand than many of the conventional dash-related tasks associated with driving. Antin et al. (1986) showed that a shift in driver's scan patterns occurred when using the navigator. Instead of glancing at the roadway for relatively long periods, say 5 seconds, drivers time-shared between the roadway and the navigator with glance durations of 1.5 to 1.9 seconds. Furthermore, there was a narrowing of the scan pattern with the navigator. Drivers tended not to glance to the right or left of center as much when using the navigator.

While it is true that scan patterns changed, it is also true that there were no accidents or near misses during any of the runs. This suggests that drivers drew upon spare resources to perform the navigation task. However, more substantiation is needed to confirm such a hypothesis.

Because drivers' scan patterns are changed when using the navigator and because the primary input when driving is visual, it is very important to gain an understanding of the changes that take place and the reasons for them. This research was directed toward helping to obtain such an understanding. In particular, it was directed at determining the degree to which drivers can subordinate navigator attentional demand to driving task demand when necessary.

The approach used in this research was to vary the visual attentional demand of the driving task, per se, while drivers performed simultaneous driving and navigation. If the drivers' visual scan patterns shifted toward the driving task with increases in driving task demand, it would represent evidence that the drivers could adapt and that to some extent they had been using spare resources to perform the navigation task. In other words, changes in scan patterns (i.e., increase in focus towards the forward view) would indicate that drivers could handle the extra attentional demands by subordinating the navigation task to the driving task when necessary.

To investigate the adaptation process properly in an experimental setting, it must be recognized that both anticipated and unanticipated variations in attentional demand occur in driving. Because the level and type of adaptation may differ according to type of variation in driving attentional demand, both types (anticipated and unanticipated) had to be investigated. Therefore, two experiments were planned. The first addressed adaptation of the driver to increases in anticipated demand and the second addressed adaptation to unanticipated demand.

METHOD

To assess the ability of drivers to adapt to changes in attentional demand, it was necessary to develop driving conditions in which attentional demand varied. Methods had to be developed which allowed variations to occur in both anticipated and unanticipated demand, as described earlier. This section describes the method used to achieve and use variations under controlled conditions.

Anticipated Attentional Demand - Experiment One

As the literature review has indicated, investigators have shown that attentional demand varies as a function of the roadway itself. If a roadway is narrow, winding, or otherwise difficult to drive, then attentional demand in driving increases. Drivers ordinarily can anticipate difficulties in negotiating a roadway by viewing the forward roadway through the windshield. Thus, roadway-related attentional demand is anticipated demand. Drivers have the opportunity to determine somewhat ahead of time the amount of visual resources that must be used to negotiate the roadway.

To take advantage of this form of anticipated attentional demand in an experimental setting, it was necessary to obtain numerical estimates of the roadway attentional demand. Thus, a procedure had to be devised for the first experiment that would allow the numerical assessment of roadway attentional demand and its use as an independent variable.

The procedure made use of roadways which, for the most part, were lightly traveled and varied in terms of sight distance, curvature, road width, and lane restrictions. The roadways chosen were divided into segments which varied in length from approximately 30 meters to 350 meters. A new roadway segment would begin when the variations in the roadway were believed to cause a change in the attentional demand level. Subsequently, two different types of assessment were developed for rating the attentional demand of each individual roadway segment: objective and subjective. The term "objective" is used here to describe an approach based on physical measurement of roadway parameters. The term "subjective" on the other hand, is used to describe an approach based on drivers' opinion. It should be clearly stated that the subjective ratings were obtained by persons who were knowledgeable researchers in the area of attentional demand. These persons <u>were</u> <u>not</u> novices.

<u>Objective ratings.</u> The objective measures gathered in this experiment were composed of measurable geometric quantities. Certain measures were chosen to represent the objective rating scheme based upon knowledge of factors that cause attentional demand to increase. Sight distance, curvature, road width, and lane restriction were the geometric quantities that were gathered. It was felt that

as these specific measures varied, attentional demand would vary accordingly. It was also decided that certain roadway measurements had a greater effect on the attentional demand variation. Thus, each category of roadway measurement was weighted according to its importance in changing the attentional demand required to travel each roadway segment. The roadway measurement calculations were as follows.

Equations were developed for each measurement with the outcome equaling a number between 0 and 100. Zero represented the lowest possible level of attentional demand and 100 equaled the highest possible level.

The equations for each roadway measurement were as follows:

Sight Distance:

$$A = 20 \log_2 \frac{500}{S_D} \tag{1}$$

where S_D is the sight distance in meters. If S_D was greater than 500 meters, then A was set equal to zero. Similarly, if S_D was less than 15.6 meters, A was set equal to 100.

Curvature:

$$B = R^{-1} \left(\frac{100}{R^{-1}_{\max}} \right) \tag{2}$$

where R^{-1} is the inverse radius of curvature and R^{-1}max is the maximum value of the inverse radius of curvature across the experiment. R^{-1}max was set at 0.054/meter.

To calculate the value of R^{-1}, the following equation was used:

$$R^{-1} = \frac{2\pi(\Delta\theta)}{360X} \qquad (3)$$

where X is the arc length in meters along the curve and $\Delta\theta$ is the change in direction in degrees between the beginning and end of the curve.

Lane Restriction:

$$C = -40S_o + 100 \qquad (4)$$

where S_o is the distance of the closest obstruction to the roadway (i.e., telephone pole, fence, ditch) measured in meters. If S_o was greater than 2.5 meters, C was set equal to 0.

Road Width:

$$D = -36.5\ R_w + 267 \qquad (5)$$

where R_w is the road width (2 lanes) in meters. If the width was greater than 7.3 meters, then D was set equal to zero. Similarly, if the width was less than 4.56 meters, D was set equal to 100.

Once the measures were calculated for each roadway segment, they were combined using a weighted equation. Sight distance was weighted most heavily, followed by road curvature, and then lane restriction. Road width was weighted least heavily. The equation for calculating the attentional demand rating for each segment was as follows:

$$Q = 0.4A + 0.3B + 0.2C + 0.1D \qquad (6)$$

where $0 < Q < 100$.

Subjective ratings (preliminary experiment). The subjective measures were obtained in conjunction with the objective measures because it was not certain that the objective roadway measures would best represent the variability of attentional demand. To obtain the subjective ratings, five graduate students in the human factors engineering group at Virginia Polytechnic Institute and State University participated in a preliminary study. These subjects were considered to be well acquainted with the concept of attentional demand. Each subject was first asked to read a set of instructions that described the experiment. (See Appendix A for these instructions.) Next, a map was presented to show what roads the subject would be driving. After studying the map, the subject was shown a rating scale in which the value one represented the lowest level of attentional demand and nine represented the highest level of attentional demand. (See Appendix B for this rating scale.) Next, the subject was told what to consider when asked to give a subjective rating. Considerations were:

1. The ability to look away from the roadway,
2. The type of roadway being driven (straight versus curved),
3. The possibility of unanticipated traffic, and
4. The effects of intersections and having to

interact with other vehicles.

Each subject twice drove the roadways used for this study. The first time was to let the subject become acquainted with the varying levels of attentional demand. The second time the subject called out numbers from one to nine at the beginning of each roadway segment. To inform the subjects of the segment starting points, one of the experimenters used the word "now." Subjects were instructed to then respond verbally with their numerical ratings. The numbers were then averaged across subjects to obtain the subjective attentional demand rating for each segment.

Main experiment data gathering. After the assessment of objective and subjective attentional demand was completed, the main data gathering experiment was planned and carried out. For this experiment, new subjects navigated the same two routes for which the objective and subjective attentional demand assessments had been made. The data runs over the two routes were counterbalanced. The first data run commenced in the early part of the afternoon, and the second began shortly after completion of the first. Subjects were run on all days of the week.

The first route required subjects to navigate predominately on two-lane rural roadways. The total drive time was approximately 20 minutes, and the total length of this route was approximately seven miles. For the most part the roadway had a high degree of curvature with rolling hills and a limited site distance. For the last five minutes of the route, subjects drove on a two-lane highway with straighter sections and longer site distances.

The beginning of the second route required subjects to travel on the same two-lane highway as described above. The end of this run (3 minutes) had subjects travel on curved, hilly roadways quite similar to the roadway traveled at the beginning of the first route. The total mileage traveled was approximately eight, and run time was approximately 20 minutes. As indicated, presentation of the two routes was counterbalanced.

Experimental design - experiment one. The experimental design was an n x 3 x 2 mixed factors design. Figure 1 shows the overall design, with age having three levels, gender having two, and attentional demand having n levels as described below. Gender and age were, of course, between-subjects variables and attentional demand was a within-subjects variable.

Attentional demand levels. The experimental design was devised in such a way that both regression and analysis of variance techniques could be used. For the regression analyses, the objective and subjective ratings of each individual roadway segment of the two runs were used as levels of attentional demand. There were in all 186 segments. Thus, for regression purposes, n was equal to 186. Thereafter, the 186 segments were rank ordered

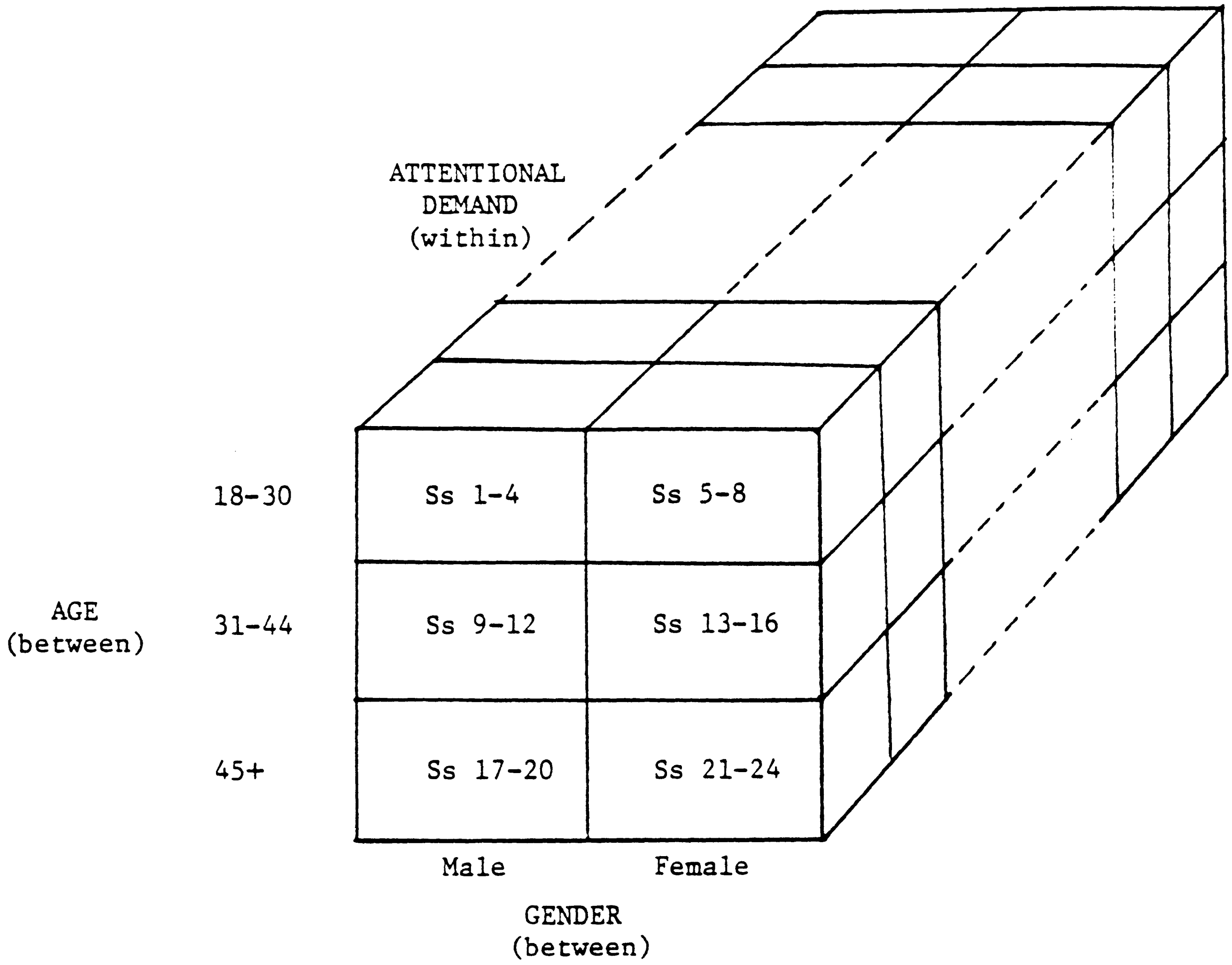

Figure 1. Experimental Design for Experiment One (Anticipated Demand Study).

according to their ratings and then divided into thirds labeled low, medium, and high. These three divided categories then served as levels of the independent variable for analysis of variance purposes. Thus, for the analysis of variance, n was equal to 3. Figure 2 depicts the different uses of the attentional demand independent variable.

Subjects and subject factors. Twenty-four subjects participated in this experiment. Subjects first had to meet certain criteria which are discussed in the procedure section of this thesis.

The subject factors were age and gender. Subjects were divided into three age categories as follows: 18 to 30, 31 to 44, and greater than 44 years old. Ages were uniformly distributed within each cell. Twelve male subjects and 12 female subjects participated in this research. There were four males and four females in each of the three age groups.

Dependent measures. Eye movement data were collected to assess where the subject was looking while navigating to a destination. These data were divided into seven different categories: (1) roadway center, (2) roadway off-center (3) signs, (4) displays/controls (dash), (5) mirrors, (6) navigator (Etak), and (7) other. Data were gathered by roadway segment. The specific measures obtained are defined in the dependent variables section for

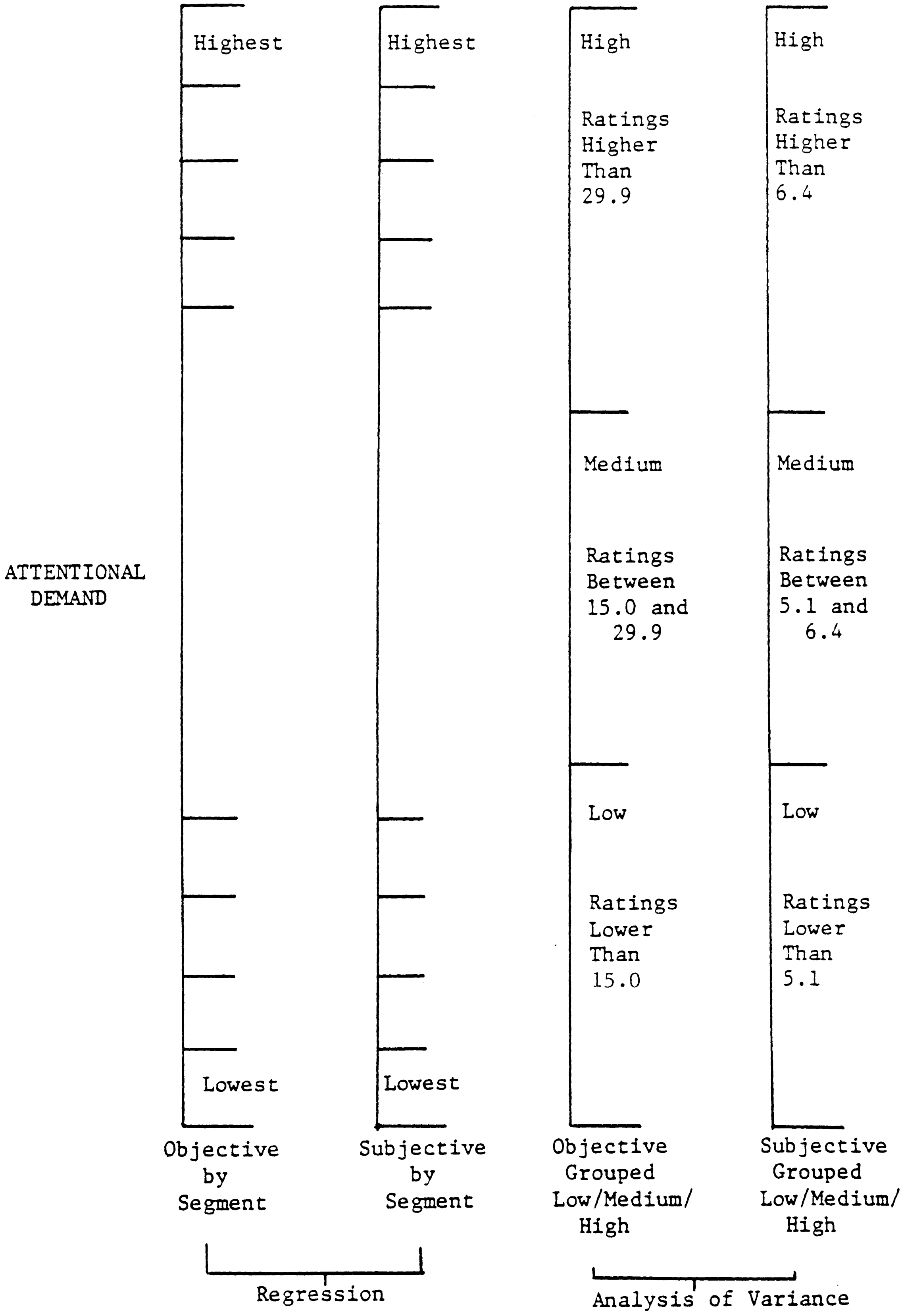

Figure 2. Uses of the Attentional Demand Independent Variable.

Experiment One.

Unanticipated Attentional Demand - Experiment Two

As indicated earlier, changes in driving attentional demand are unanticipated in many situations. To assess the ability of drivers to deal with changes in unanticipated driving demand while navigating, a method had to be developed in which unanticipated demand could be assessed and used as an independent variable.

It is certainly true that a good deal of unanticipated attentional demand in driving is a result of not knowing what other drivers, cyclists, or pedestrians might do. As a result, certain vehicles and pedestrians must be monitored closely if there is a chance that their paths may conflict with the driver's vehicle. Thus, traffic situations often cause increases in unanticipated attentional demand.

Fundamentally, then, Experiment Two involved having drivers (subjects) navigate along routes in which traffic was moderate to heavy. Three routes were used for the study. Each of the routes was approximately eight miles long and required navigating past industrial plants and shopping centers, and along main streets of small towns. Each route required approximately 25 minutes to drive.

Only portions of the three runs were used for data analysis. These portions were selected so that effects of unanticipated demand could be compared with other normal driving situations. More specifically, "incidents" were selected from the gathered data. An incident was operationally defined as a situation in which the driver had to monitor closely the forward view to avoid a potential accident. An example of an incident would be the situation in which an oncoming vehicle makes a left turn directly in front of the driver's vehicle. Unless the driver monitors the situation closely, there is some likelihood of an accident.

Incidents, as defined here, normally require careful watching by the driver and therefore require high visual attentional demand. Because of the unpredictable nature of incidents, they are largely unanticipated and do not allow the driver to plan ahead of time how to use visual resources. The driver either pays attention to them or risks an accident.

For purposes of comparison, non-incident control conditions also had to be obtained. Two control conditions were specified for every incident, one in light traffic and one in heavy traffic. The control condition data were taken from intervals having similar roadway conditions to those where the incident occurred but during which no incident occurred. In other words, the two control condition environments were similar to the incident condition but without an incident.

Experimental design - experiment two. The experimental design for the second experiment was a 3 x 3 x 2 mixed factor design. The unanticipated attentional demand variable had three levels: incident, light-traffic non-incident, and heavy-traffic non-incident as previously described. This variable was called Traffic Type. Subject factors were the same as in Experiment One. Age had three levels.

Subjects. Subjects who participated in Experiment One also participated in Experiment Two. Thus, 24 subjects participated, 12 males and 12 females, with 8 subjects in each age group, as shown in Figure 3.

Dependent measures. The eye position recordings for this experiment were similar to those used in Experiment One. However, instead of gathering data by segment, data were gathered by situation, as described above. The specific measures computed are defined in the dependent variables section for Experiment Two.

Apparatus

The apparatus for the two experiments is similar to that of Dingus et al. (1986).

Test vehicle. The test vehicle was a 1985 Cadillac Sedan deVille. The vehicle was equipped with such options as power mirrors, fuel data center, stereo radio/cassette deck, digital dashboard, cruise control, and electronic climate control.

Etak navigator. The five components of the Etak

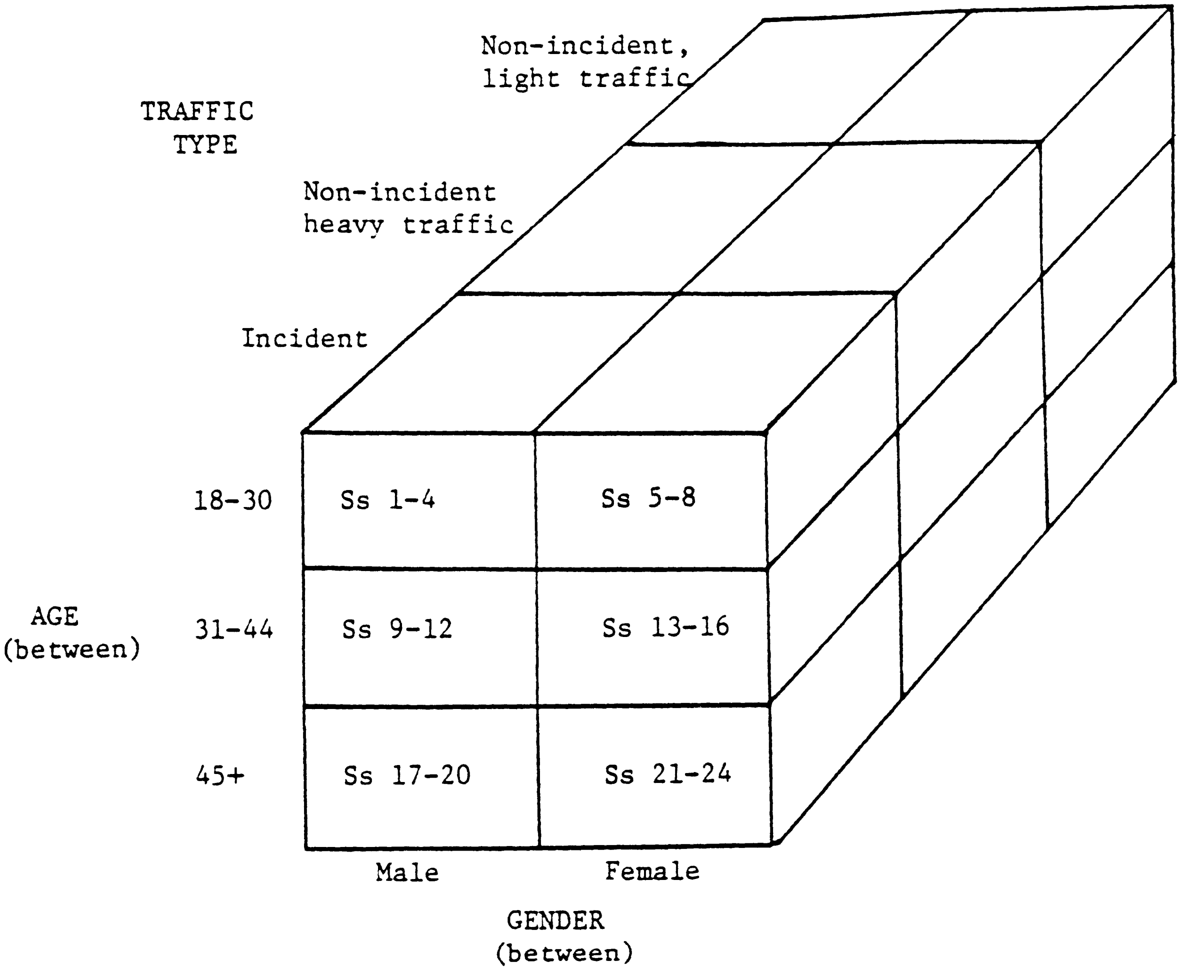

Figure 3. Experimental Design for Experiment Two (Unanticipated Demand Study).

navigator system were installed in their usual positions on the research vehicle. The display unit was installed on the dashboard, centered between the middle air conditioning vents. The entire unit measured 10.5 cm high by 13.0 cm wide. The monochrome CRT screen where the map was shown measured 7.3 cm high by 9.5 cm wide. The tape drive unit was mounted on the floor beneath the center of the dashboard. The computer system was mounted in the right hand side of the trunk. The fluxgate compass was mounted under the headliner, and the wheel sensors were installed on the (non-driven) rear wheels of the research vehicle.

Eye scanning camera recorder system. The system was composed of two cameras and two recorders. One of the cameras was mounted on the hood of the research vehicle and faced into the car to record the subjects' eye movements. To reduce the effects of glare, a metal shroud was placed over the lens of the camera and extended to the windshield. The second camera, fitted with a wide angle lens, was mounted on the roof of the vehicle. This camera recorded the forward view of the roadway. The video was recorded on tape via two recorders which were located in the back seat of the research vehicle.

The experimenter in the back seat recorded eye glance durations on-line via a single pushbutton and video monitor, a Setchell-Carlson Model 12M918, which showed the subject's face (as obtained by the hood mounted camera).

To reduce glare on the video monitor, it was fitted with a custom glare-shield. During a data run, the back seat experimenter depressed the pushbutton while the subject's eyes were stationary. When the subject's eyes moved, the experimenter released the pushbutton until the subject's eyes were stationary again. These eye measures were recorded on-line via a custom interface connected to an IBM/PC located in the back seat.

Tones of different frequencies were associated with consecutive pushbutton presses and recorded onto the audio channel of each recorder. These tones helped during data reduction to synchronize and ensure that eye glance measures were associated with the correct eye glance viewed on the video monitor.

The route completion and driving classification measures were collected by the front seat experimenter. Pushbuttons located on a panel held by the experimenter were depressed to collect the various measures.

Route completion times were collected to record the beginning and end of each run. At the beginning of a run, the experimenter depressed the corresponding pushbutton and data collection began. Once the subject had reached the correct destination, the route end pushbutton was depressed and data collection stopped. The data gathered between the two button presses were then stored onto diskettes via the IBM/PC.

Driving classification measures were also collected by the front seat experimenter by depressing one of three different pushbuttons. In Experiment One, when the beginning of the first segment was reached, the experimenter would depress the first of the three buttons. Upon reaching the beginning of the second segment, the second button would be depressed; the third button was depressed when the third segment began. When the fourth segment began, the first pushbutton was depressed again. The order of depressing the buttons continued until the last segment was reached. Each pushbutton press was stored at the interface and simultaneously sent to the IBM/PC. The data collection was done in this way to separate the data collected for each segment. Once the attentional demand levels had been calculated for each segment, the levels could be incorporated into the segment data.

Safety equipment. The research vehicle carried a fire extinguisher, radio, and first aid kit at all times. The vehicle was also equipped with a second brake pedal located on the floor of the front seat experimenter's side of the vehicle. Safety belts were used at all times.

Data reduction equipment. The roadway and subject video tapes were played back in the laboratory via two additional monitors and video recorders. Once eye glance classification data were collected from the video tapes, these data were merged with the data collected by the

IBM/PC located in the vehicle using a second IBM/PC located in the laboratory. Subsequently, data were transferred via a localnet connection to the University's central computing facility for statistical analysis.

Procedure

Instructions and informed consent. A subject first read the introductory material and informed consent (see Appendix C). The experimenters answered any questions the subject had pertaining to what was read, and then the subject signed the informed consent form.

Subject screening. Next, the subject had to pass an informal hearing and formal vision test (with 20/40 near vision and 20/40 far vision). The subject was also asked if he or she was familiar with any of the destinations. Only those subjects who were unfamiliar with the navigation destinations were permitted to participate in this experiment. The subjects were also required to fill out a medication and personal history questionnaire. If the subjects were unfamiliar with the routes, if they passed the hearing and vision tests, and if they had no conditions which might have interfered with their driving ability, they were considered as qualified to participate in this study.

Reading the vehicle and Etak manuals. The subject read information concerning the vehicle's basic control and display locations and operation. This information was selected from the vehicle owner's manual. Only the information that was necessary to control the car was presented, such as how to operate the turn signal and windshield wipers. Thus, information about the cruise control, radio, etc., was not presented.

Finally, the subjects read about the navigator and how to operate it. This information was selected from the Etak Navigator Owner's Manual (Etak, 1986b). Again, only information required for study completion was presented.

Training

Session I. The subjects were trained while seated in the driver's seat of the experimental vehicle. While the car was in Park, all the controls and displays read about in the car owner's manual were demonstrated by the front seat experimenter. The subject was then asked to operate each control. Once the subject was familiar with the vehicular controls and displays, the experimenter activated the map display and demonstrated all the different functions that the subject had read about in the navigator owner's manual. The subject was then asked by the experimenter to perform the navigator functions. This portion of the training was completed when the subject had successfully performed all the vehicle control and navigator functions. The approximate time to complete this segment of training was 20 minutes.

For the next portion of training the front seat experimenter took the driver's position, and the subject was asked to direct the front seat experimenter to a destination while using the Etak. By using this approach the subject could view the moving-map display in action. It was felt this might help to decrease the novelty effect more quickly. The subject was also allowed to ask questions pertaining to the Etak during the training. Once the subject had correctly directed the experimenter to the destination, the subject took over the driving task and was asked to navigate to the next destination a short distance away. Upon reaching this destination, the subject was asked to navigate to a third destination, also a short distance away. After the subject successfully arrived at the third destination, Session I was considered complete. This segment of Session I usually required 35 minutes to complete. A break followed which lasted up to one hour.

Session II. Session II began with the subject again being asked to navigate to another destination. This was to ensure that the subject had retained the information necessary to navigate using the navigator. Once the subject had reached this destination, the subject was asked if he or she felt comfortable using the navigator to get to a destination without asking questions. If the subject felt comfortable, data collection began. If not, the subject drove to another destination, and data collection began thereafter. It should be noted that all subjects reported feeling confident using the navigator after completion of the last training run. Session II, up to this point, lasted for approximately 20 minutes.

Data run. The subject drove to the starting point of the first run and was instructed to park the car in a safe and legal place off the roadway. While parked, the experimenter in the back seat started all of the data collection equipment, including the video cameras and computer. Next, the subject had a microphone placed around the neck and was instructed to read aloud any street or directional signs used in navigating to the destinations. These verbal data were recorded on the videotape associated with the roof-mounted camera. The subject was then instructed to navigate to the first destination and to drive the route as efficiently as possible. Once the subject had planned how to begin navigating to the destination, he or she began driving.

Each data run was considered complete once the subject had reached the destination. It should be noted that if a subject took a wrong turn or missed a turn, the subject was so informed by the experimenters. The subject then returned to the correct route and continued driving. Once the destination was reached and the car was safely and legally off the road and in Park, the data stored in random access memory (RAM) in the IBM/PC were transferred to a diskette. The same procedure was followed for each run.

As indicated previously, Experiment One consisted of two data runs and Experiment Two consisted of three data runs. The five runs were performed in succession. The subject was given breaks between runs as needed to refresh. Upon completion of the last run, the front seat experimenter drove the vehicle back to the University, where the subject was paid, debriefed, and dismissed. The time required for data gathering for all five runs was approximately two hours.

DEPENDENT VARIABLES - EXPERIMENT ONE

The main purpose of this experiment was to determine if subjects would change their eye glance behavior as objective and subjective anticipated attentional demand levels changed. Five dependent variables were included in both the objective and subjective data analysis. These variables measured certain eye scanning behaviors while driving using the navigator to arrive at the designated destinations. The dependent variables are described below followed by the analyses which were conducted on them.

Dependent Variable Definitions

Probability of a glance to the center roadway, mirrors, and dashboard (EYEDRIVE). This variable is a summation of the probabilities of a glance to the center roadway, mirrors, and dash. These three glance areas are considered to be essential in driving an automobile. To calculate the probability of a glance to the center roadway, for example, the total time the eyes are focused on the center roadway is divided by the total time spent on all seven glance categories over a given time interval for each segment. Thus, EYEDRIVE is the sum of three glance probabilities directly associated with driving.

Probability of a glance to the Etak (EYENAV). The EYENAV variable is the probability of a glance to the Etak. This probability was obtained using the same format as EYEDRIVE. EYENAV is essentially the proportion of total time over a measurement interval (segment) in which the eyes are on the navigator.

Probability of a transition between the center roadway, mirrors, and dashboard (DRIVELINK). DRIVELINK is the summation of the probabilities of transitions among glances from three of the seven different categories described in the method section (center roadway, mirrors, and dashboard) and is strictly concerned with glance areas related to the driving task. To obtain this probability, the number of transitions between the center roadway and mirrors, between the mirrors and dashboard, and between the dashboard and center roadway are summed together and divided by the total number of transitions among any of the seven categories for the specified time interval. Each segment transition probability is then added together for each level of attentional demand.

Average time spent glancing at the center roadway (AVECNTR). AVECNTR is the total amount of time per glance spent glancing at the center roadway divided by the total number of glances to the center roadway for each attentional demand level. Thus, it is the average amount of time per glance to the center roadway.

Average time spent glancing at the Etak (AVEETAK). This variable is the average amount of time per glance spent glancing at the Etak. It is calculated by summing the total amount of time spent glancing at the Etak divided by the total number of glances to the Etak.

RESULTS - EXPERIMENT ONE

Regression Analyses

Linear regression analyses were conducted with both the objective and subjective independent variables for both EYEDRIVE and EYENAV. Thus, four regression analyses were carried out. Each regression line was based on approximately 4400 data points, that is 186 segments by 24 subjects.

It should be noted that one of the assumptions of linear regression analysis is that of at least interval scale data. It is possible that the subjective data are in fact non-interval because the ratings were based on opinion, although the people were given an interval scale rating sheet is a guide for use while judging the roadway segments. The reader is therefore advised to interpret these results with caution as some degree of statistical bias, either conservative or liberal, could be present.

The slope of the four regression lines were of particular interest because significant non-zero slopes would be an indication of adaptation by drivers to roadway anticipated attentional demand changes. Table 1 presents the slopes of the four regression lines and shows that all four were significantly greater than zero.

To gain insight into the distribution of the data, the four regression lines were plotted along with averages performed on the data. The large number of points used in

Table 1

Slopes, t values, and p values for Regression Analyses on Objective and Subjective Data regressed against Probability of a Glance to Roadway Center, Mirrors, and Dashboard (EYEDRIVE) and Etak (EYENAV).

	Objective Data			Subjective Data		
	Slope	t	p	Slope	t	p
EYEDRIVE	0.0020	8.35	0.0001	0.029	11.07	0.0001
EYENAV	-0.0026	-9.57	0.0001	-0.032	-12.30	0.0001

the regression could not meaningfully be plotted. Figure 4 is a plot of EYEDRIVE versus the objective rating, and Figure 5 is a plot of EYENAV versus the objective rating. In these two plots data are averaged over one-unit intervals of the abscissa and plotted at the midpoint of the interval. If there were no data within a given one-unit interval, no point was plotted. Figures 6 and 7 are corresponding plots for the subjective ratings of attentional demand. In this case, the average values of EYEDRIVE and EYENAV for each 0.1 interval of an abscissa unit are plotted. Since there were five preliminary subjects and integer ratings were normally given, all data points fell at values 0.1 unit apart. Again, lack of a plotted point at a given abscissa value indicates absence of data. The plots show clearly that EYEDRIVE increases for increasing anticipated attentional demand and EYENAV decreases for increasing attentional demand. Also, the subjective ratings results in less scatter of the averaged data about the regression lines.

Correlation Analyses

To determine the strength of association among pairs of variables, a Pearson product-moment correlation analysis was conducted. The dependent variables EYEDRIVE and EYENAV were correlated with the objective ratings, with the individual elements of the objective ratings, and with the subjective ratings. However, none of the correlations were

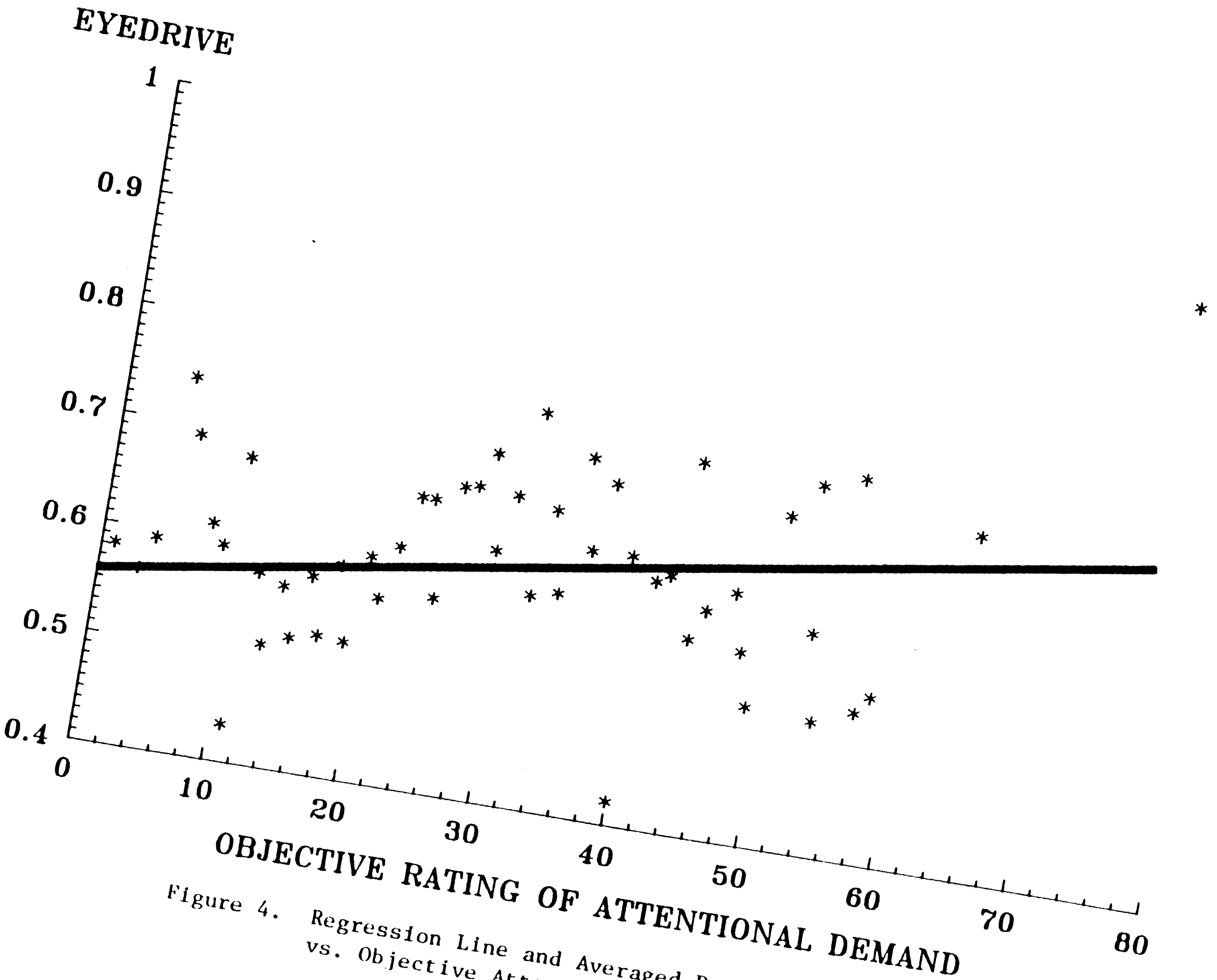

Figure 4. Regression Line and Averaged Data for EYEDRIVE vs. Objective Attentional Demand.

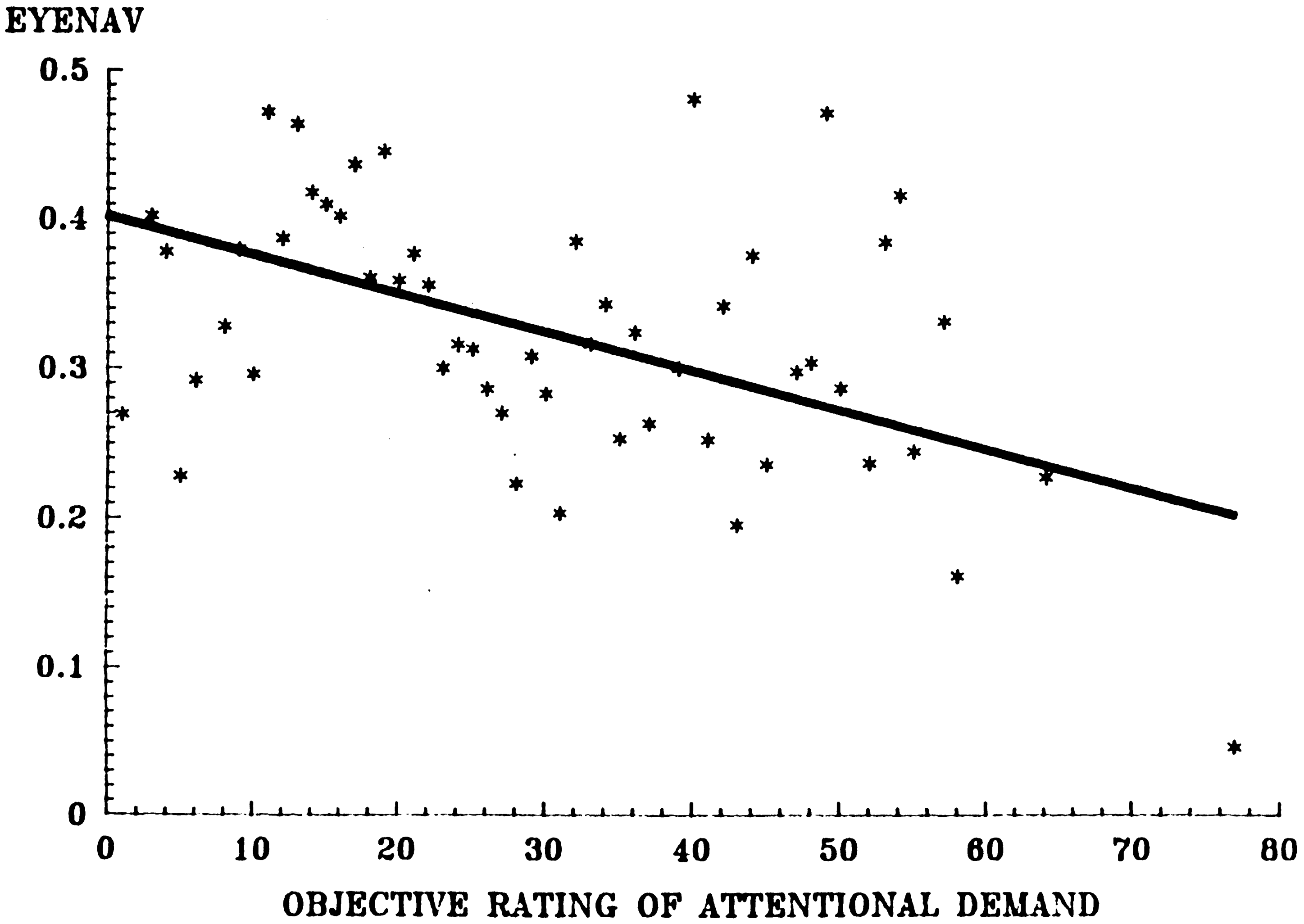

Figure 5. Regression Line and Averaged Data for EYENAV vs. Objective Attentional Demand

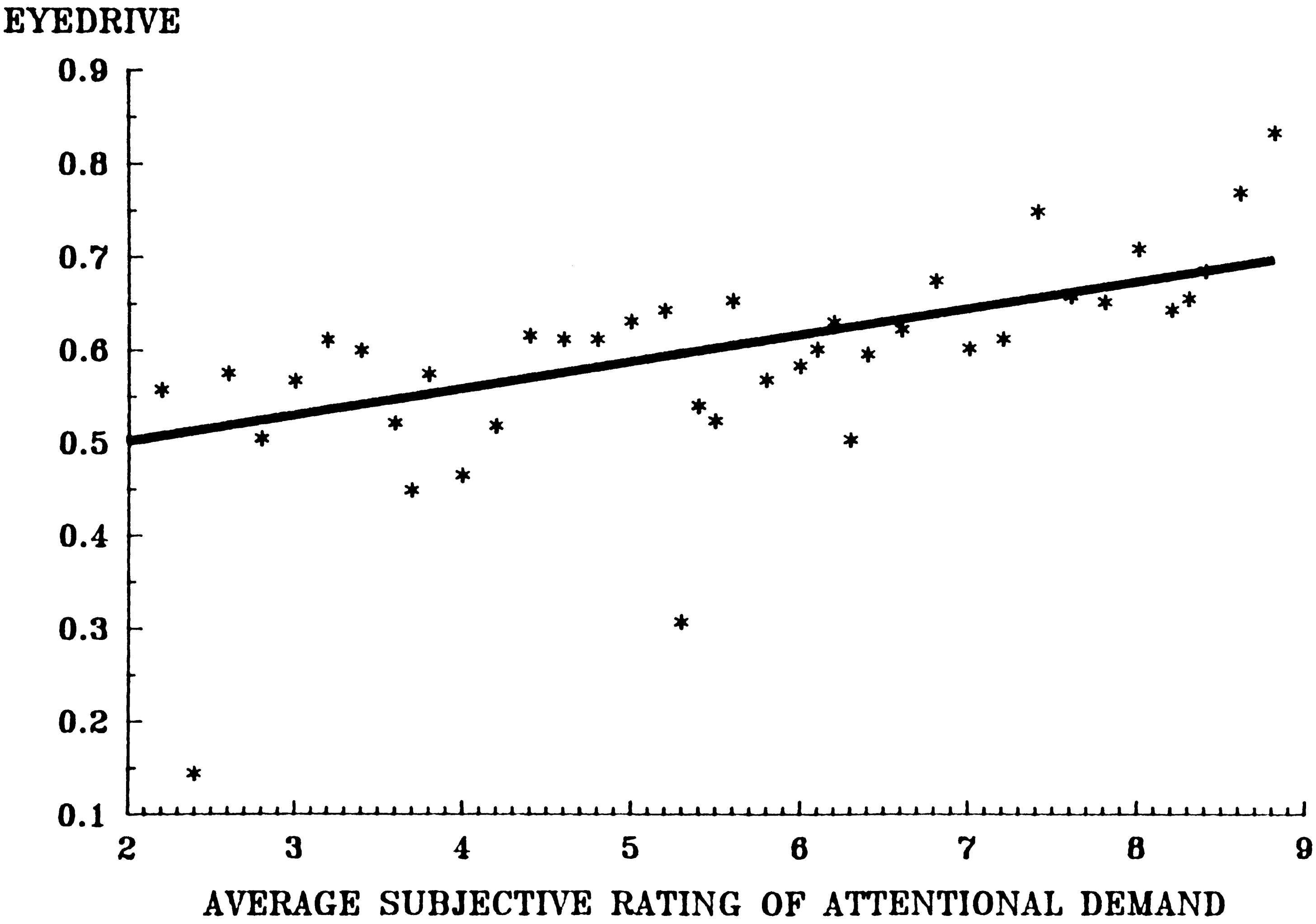

Figure 6. Regression Line and Averaged Data for EYEDRIVE
vs. Subjective Attentional Demand.

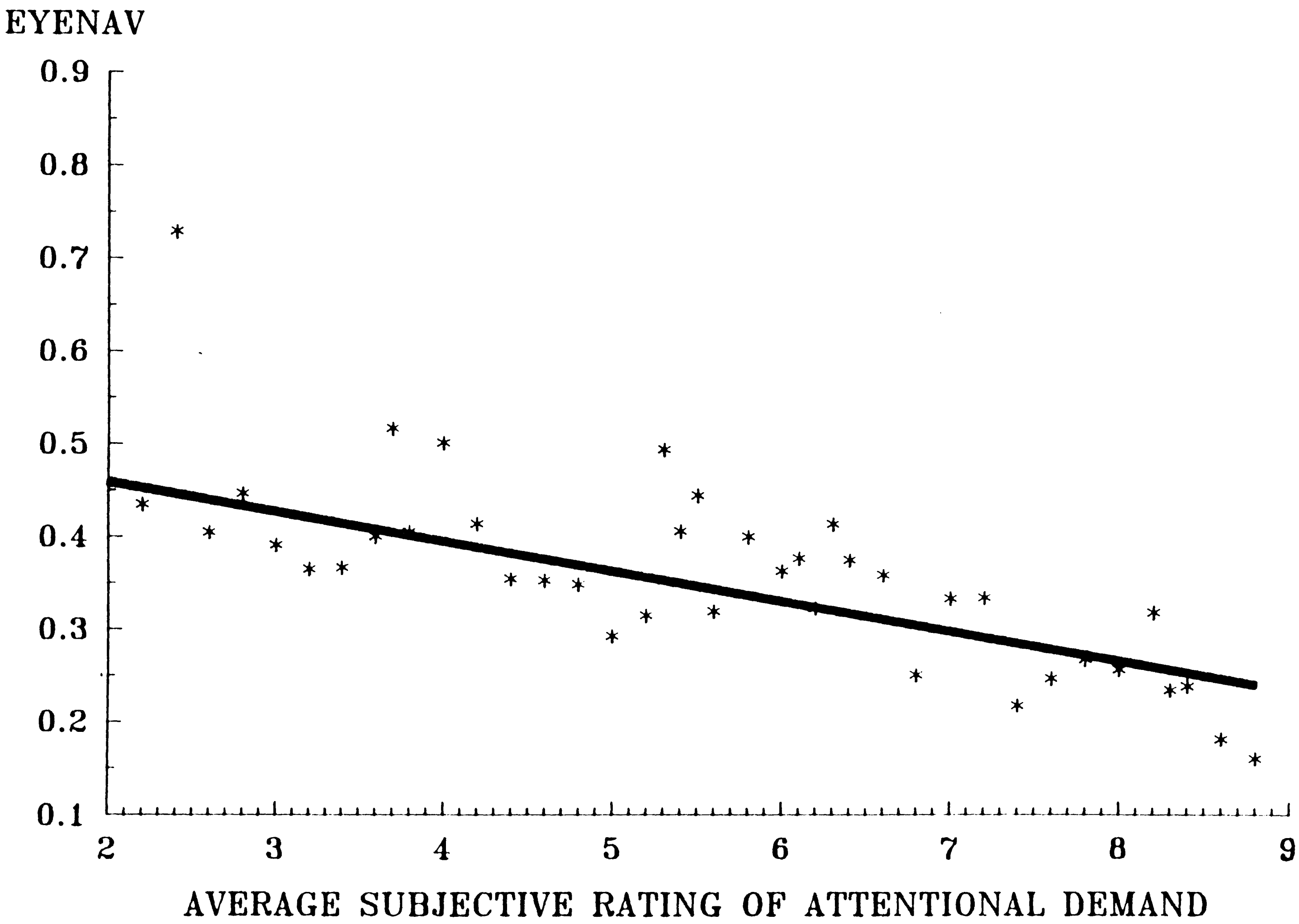

Figure 7. Regression Line and Averaged Data for EYENAV vs. Subjective Attentional Demand.

significantly difference from one another at the 0.05 level. The results appear in Table 2.

The correlation analyses indicate that even for the subjective rating the strength of association with EYEDRIVE and EYENAV is not particularly high.

An additional set of correlation analyses was conducted on the independent variables and their components. The results are presented in Table 3. The table shows, in particular, that the subjective and objective ratings were highly correlated (0.72) and that subjective ratings were correlated with sight distance (0.65) and to a lesser extent with lane restriction, curvature, and road width.

Thus the correlations which were run show that while they were relatively low, the trends were in the correct direction. And the objective and subjective measures were closely related.

Analyses of Variance and Post-Hoc Tests - Objective Data

As indicated earlier and depicted in Figure 2, the objective independent variable, which originally had 186 levels, was rank ordered and then divided into thirds. The three portions were then termed low, medium, and high (Figure 2). All analyses of variance and post-hoc tests were than performed based on these three levels of the independent variable.

Multivariate analysis of variance (MANOVA).

A MANOVA

Table 2

Correlation of the Independent Variable Measurements with Probabilities of a Glance to Driving Related Areas (EYEDRIVE) and the Etak (EYENAV).

	EYEDRIVE	EYENAV
Objective Rating	0.13*	-0.14*
Sight Distance	0.10*	-0.11*
Curvature	0.09*	-0.12*
Lane Restriction	0.07*	-0.10*
Road Width	0.05*	-0.04**
Subjective Rating	0.17*	-0.18*

* indicates p = 0.0001
** indicates p = 0.01

Table 3

Correlation Matrix of the Independent Variable.

	Sight Distance	Curvature	Lane Restriction	Road Width	Subjective Rating
Objective Rating	0.85	0.52	0.69	0.48	0.72
Sight Distance		0.25	0.33	0.25	0.65
Curvature			0.21	0.11	0.39
Lane Restriction				0.41	0.43
Road Width					0.29

all numbers are significant at $p = 0.0001$

was performed on all dependent variables (EYEDRIVE, EYENAV, DRIVELINK, AVECNTR, AND AVEETAK) for the objective data. Using the residual mean square as the error term, the MANOVA showed only attentional demand to be significant (Table 4). Gender and age were not significant, nor were any of the interactions.

<u>One-way analyses of variance (ANOVA).</u> Because there were no significant interactions in the MANOVA, one-way ANOVAs were performed on each of the dependent measures for the attentional demand independent variable. These ANOVAs are summarized in Tables 5 through 9. With the exception of EYENAV, all the dependent measures were significant.

<u>Post-hoc (Newman-Keuls) comparisons.</u> The Newman-Keuls test performed on the variable EYEDRIVE (Figure 8) revealed a significant difference between low attentional demand versus medium and high attentional demand levels. The low attentional demand level had the smallest probability of a glance to the center roadway, mirrors, and dashboard. These results indicate that during medium and high levels of attentional demand, subjects glance at areas specifically related to the driving task more than during low levels of attentional demand.

Figure 9 shows the Newman-Keuls test performed on the variable DRIVELINK. While medium and high attentional demand values are not significantly different from one another, they are significantly different from the low

Table 4

Objective Attentional Demand MANOVA.

Source	*df*	*F*	*p*
Attentional Demand (D)	2	7.30	0.0001
Gender (G)	1	2.50	0.0806
Age (A)	2	1.72	0.1254
A x D	4	0.67	0.8469
G x D	2	0.88	0.5596
A x G	2	1.49	0.1968
D x A x G	4	0.58	0.9184
Subject/A,G	18		
D x Subject/A,G	36		

Table 5

Objective Attentional Demand One-Way ANOVA for EYEDRIVE.

Source	df	MS	F	p
Attentional Demand	2	0.0402	6.16	0.0043
Subject x Attentional Demand	46	0.0065		

Table 6

Objective Attentional Demand One-Way ANOVA for EYENAV.

Source	*df*	*MS*	*F*	*p*
Attentional Demand	2	0.0009	0.24	0.7909
Subject x Attentional Demand	46	0.0038		

Table 7

Objective Attentional Demand One-Way ANOVA for DRIVELINK.

Source	*df*	*MS*	*F*	*p*
Attentional Demand	2	0.0080	6.79	0.0026
Subject x Attentional Demand	46	0.0012		

Table 8

Objective Attentional Demand One-Way ANOVA for AVECNTR.

Source	*df*	*MS*	*F*	*p*
Attentional Demand	2	0.8129	5.63	0.0065
Subject x Attentional Demand	46	0.1444		

Table 9

Objective Attentional Demand One-Way ANOVA for AVEETAK.

Source	*df*	*MS*	*F*	*p*
Attentional Demand	2	1.7740	20.86	0.0001
Subject x Attentional Demand	46	0.0850		

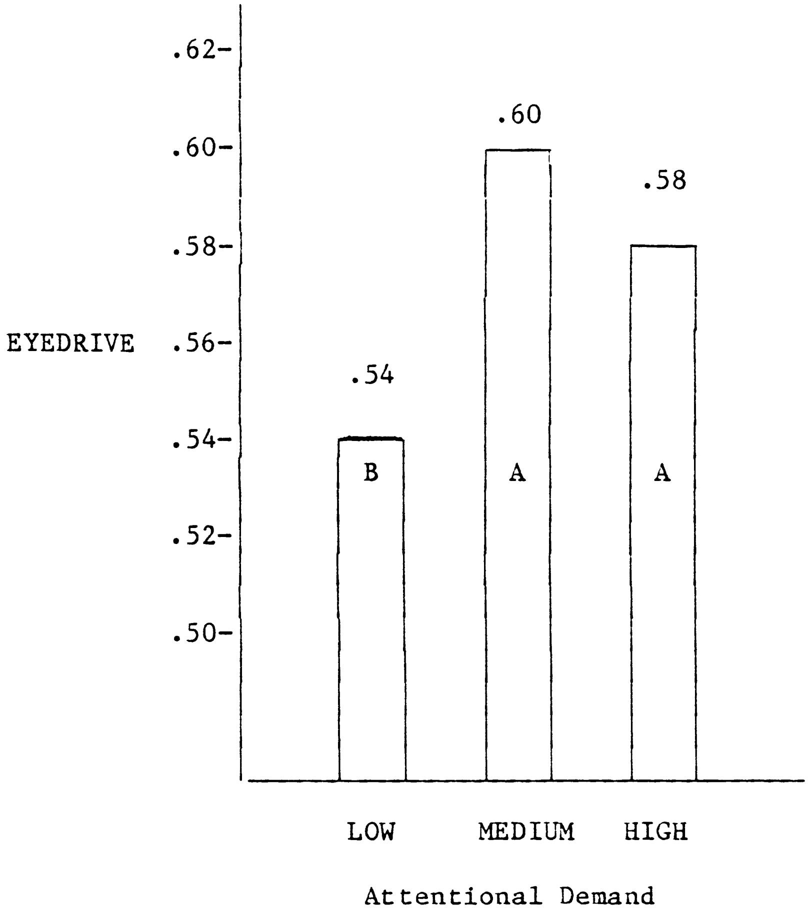

Figure 8. Probability of a Glance to Roadway Center, Mirrors, and Dashboard (EYEDRIVE) by Attentional Demand for Objective Data. (Groupings are based upon Newman-Keuls multiple comparisons. Different letters indicate attentional demand differences at the 95% confidence level).

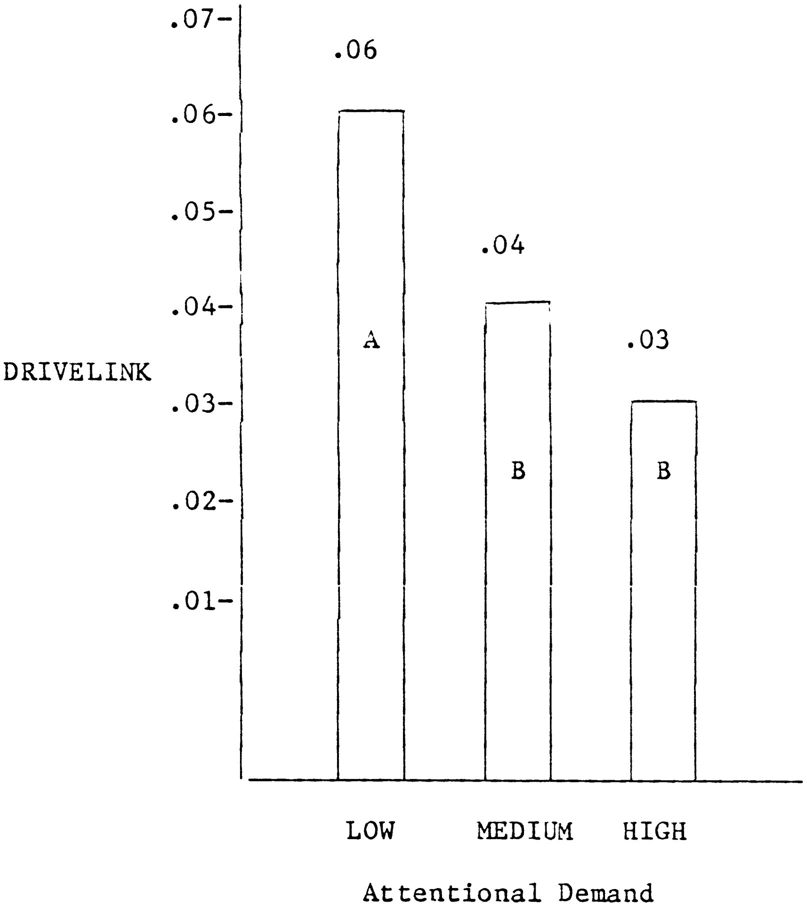

Figure 9. Probability of a transition between Roadway Center, Mirrors, and Dashboard (DRIVELINK) by Attentional Demand for Objective Data. (Groupings are based upon Newman-Keuls multiple comparisons. Different letters indicate attentional demand differences at the 95% confidence level).

attentional demand level. Low attentional demand has the highest probability of a transition among the three driving related categories. Thus, subjects were making more transitions between the driving related categories during levels of low attentional demand than during medium and high levels.

The AVECNTR Newman-Keuls comparison showed low attentional demand to be significantly different from medium and high attentional demand, while medium and high attentional demand were not significantly different from one another. This effect is shown in Figure 10. For the low attentional demand level a subject's average glance to the center roadway was longer than for the other two categories.

A Newman-Keuls comparisons test was performed on AVEETAK (Figure 11) and showed all the levels of attentional demand to be significantly different from one another. A subject's average glance length to the Etak was longest for low attentional demand. Interestingly, the medium attentional demand had the lowest average glance duration to the Etak, while high attentional demand fell between low and medium with regard to average glance time to the Etak.

Link value analyses. To get a better understanding for probabilities of a glance to a certain area or a transition (link) from one area to another, link value

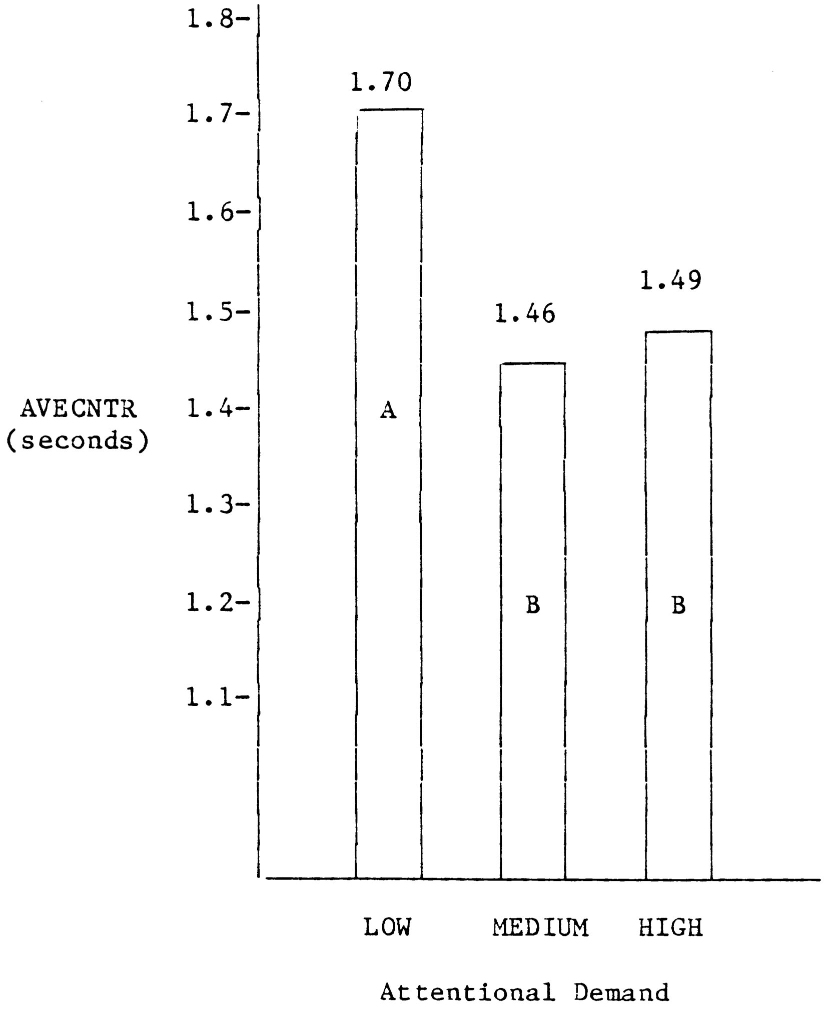

Figure 10. Average Glance Length to Roadway Center (seconds) (AVECNTR) by Attentional Demand for Objective Data. (Groupings are based upon Newman-Keuls multiple comparisons. Different letters indicate attentional demand differences at the 95% confidence level).

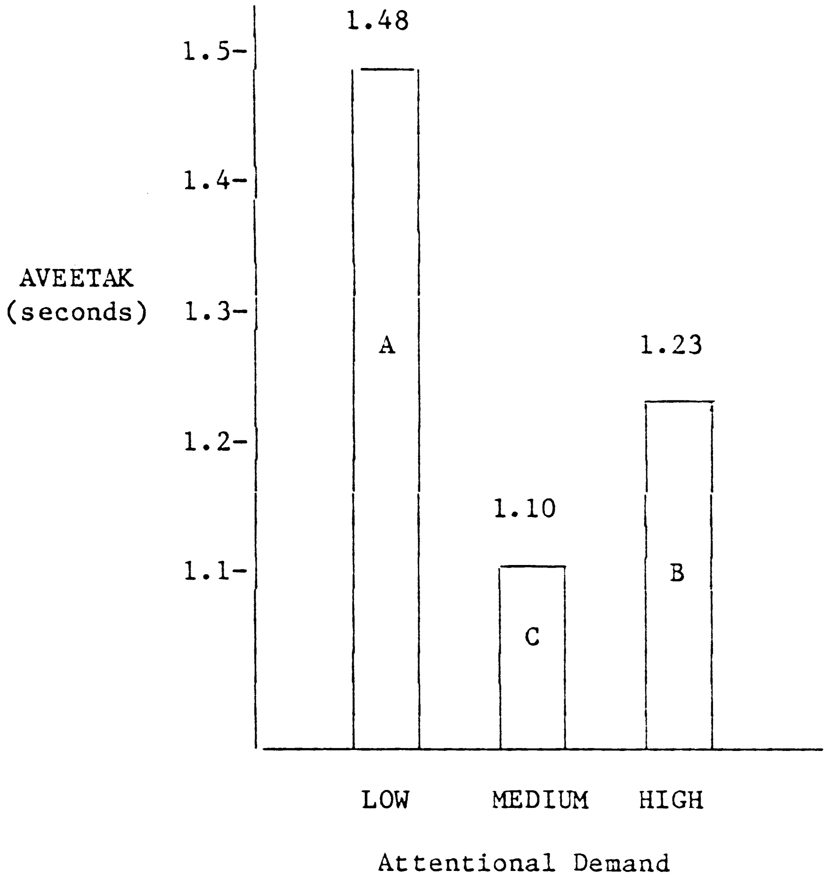

Figure 11. Average Glance Length to Etak (seconds) (AVEETAK) by Attentional Demand for Objective Data. (Groupings are based upon Newman-Keuls multiple comparisons. Different letters indicate attentional demand differences at the 95% confidence level).

diagrams were developed for each level of attentional demand and are shown in Figures 12, 13, and 14, respectively. In these diagrams, any link value probability or glance probability below a value of 0.01 is deleted. As can be seen, only a small difference in eye scanning behavior is apparent from these diagrams. Low attentional demand does have a transition probability between mirrors and roadway off-center, while medium and high levels do not. Also, the probability of transitions between the Etak and roadway (center) increases with increasing attentional demand.

Analyses of Variance and Post-Hoc Tests - Subjective Data

The subjective independent variable, like the objective independent variable, originally had 186 levels. The subjective data were rank ordered and divided into thirds in the same way as the objective data (Figure 2). Analyses of variance and post-hoc tests were then performed using the three levels of the subjective independent variable.

Multivariate analysis of variance (MANOVA). A MANOVA was performed on the dependent variables as shown in Table 10. The table reveals that only the main effect of attentional demand was significant. Gender and age were not significant; however, gender was close to the traditional $\alpha = 0.05$ level. None of the interactions was significant. These results are quite similar to those

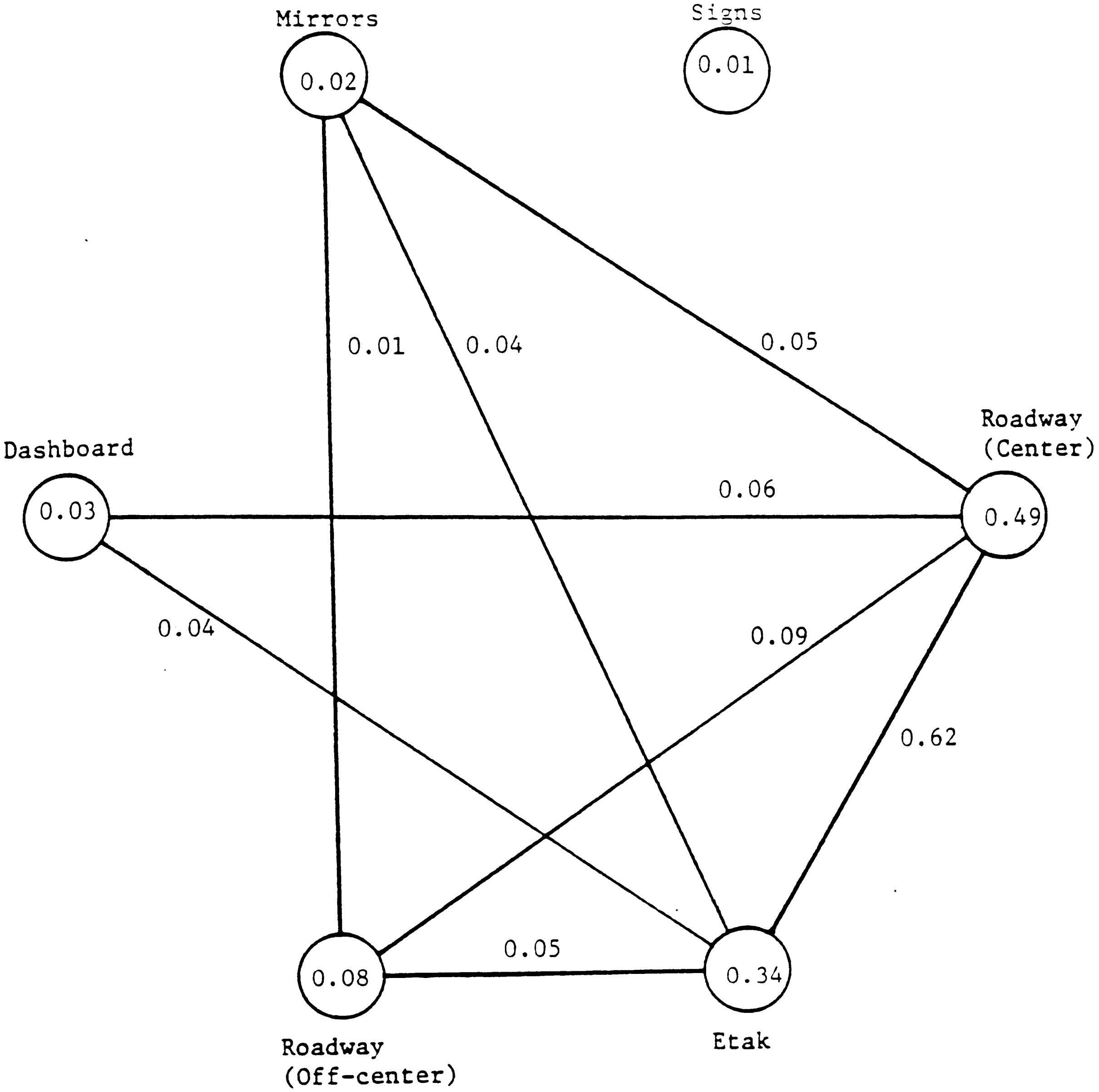

Figure 12. Glance and Link Value Probability Diagram for Low Objective Attentional Demand.

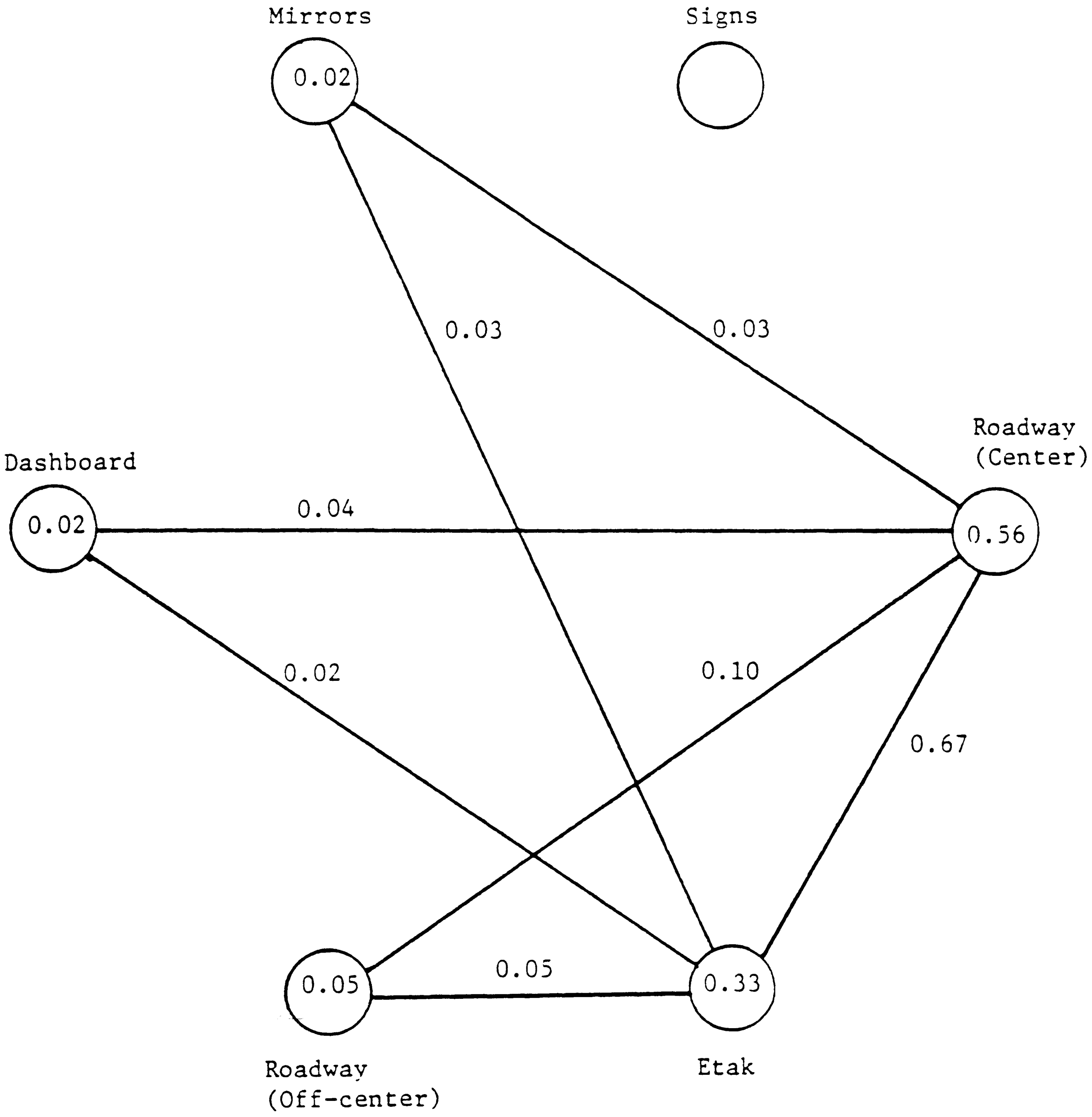

Figure 13. Glance and Link Value Probability Diagram for Medium Objective Attentional Demand.

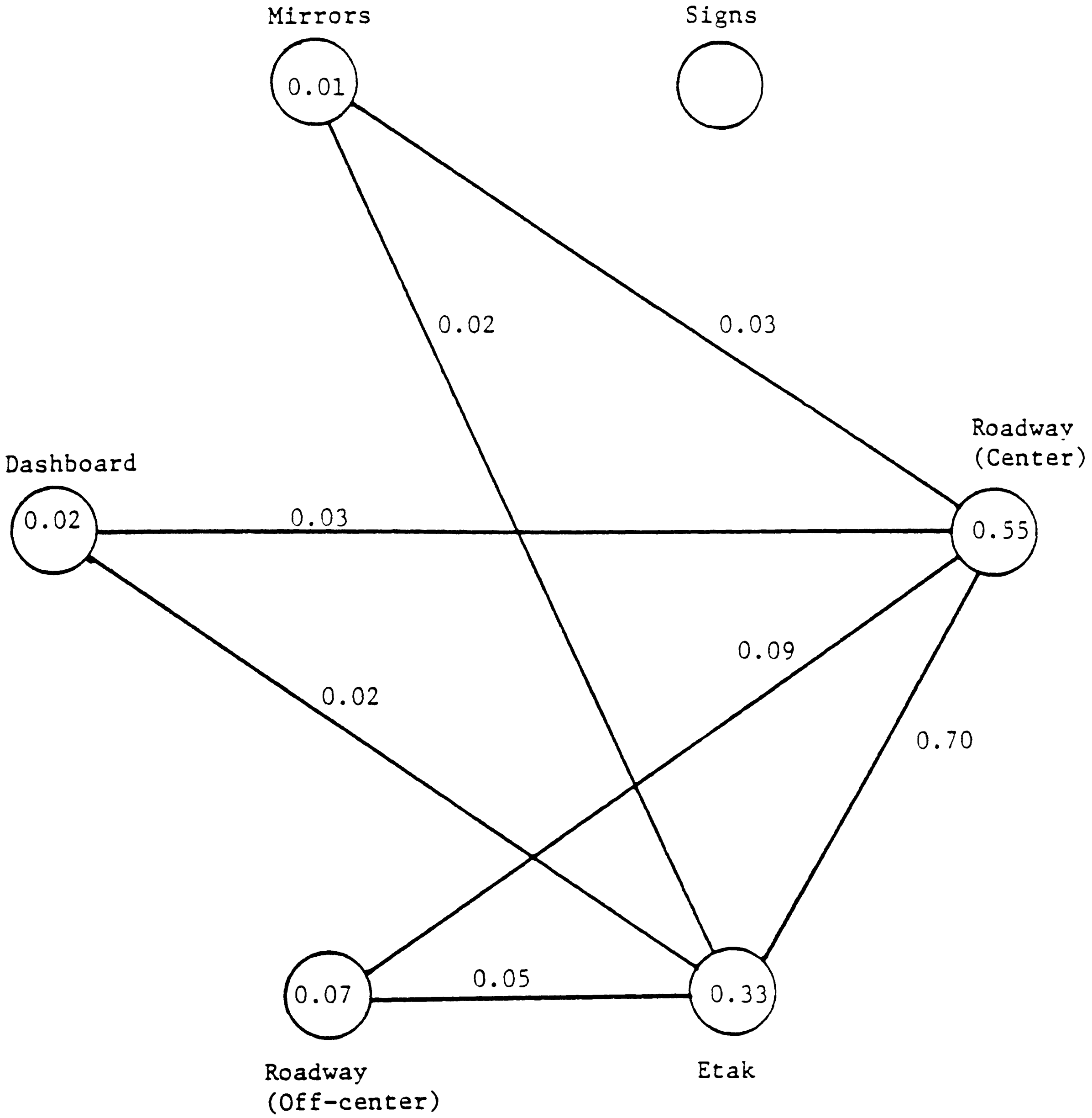

Figure 14. Glance and Link Value Probability Diagram for High Objective Attentional Demand.

Table 10

Subjective Attentional Demand MANOVA.

Source	df	F	p
Attentional Demand (D)	2	7.83	0.0001
Gender (G)	1	2.88	0.0541
Age (A)	2	1.86	0.0960
A x D	4	0.94	0.5376
G x D	2	1.04	0.4250
A x G	2	1.43	0.2190
D x A x G	4	1.20	0.2676
Subject/A,G	18		
D x Subject/A,G	36		

obtained for the objective data.

One-way analysis of variance (ANOVA). Individual one-way ANOVAs were performed on each dependent variable for the independent variable attentional demand. The ANOVAs shown in Tables 11 through 15 reveal that only AVEETAK and EYEDRIVE were significant.

Post-hoc (Newman-Keuls) comparisons. Figure 15 shows the results for the Newman-Keuls test performed on EYEDRIVE. The probability of a glance to the center roadway was lowest for low attentional demand, as well as significantly different from medium and high demand.

The Newman-Keuls test performed for AVEETAK (Figure 16) showed the low attentional demand level to be significantly different from medium and high. Medium and high attentional demand were not significantly different from one another. The low condition had the longest average glance to the Etak.

Link value analyses. The link value diagrams for the glance and transition (link) probabilities are given in Figures 17, 18, and 19. These show the probability of a glance to the category in the circled areas and the probability of a transition from one category to another next to the line going from one category to another. Low and high attentional demand diagrams have an additional link between mirrors and roadway off-center.

Additional Analyses for Gender

Table 11

Subjective Attentional Demand One-Way ANOVA for EYEDRIVE.

Source	df	MS	F	p
Attentional Demand	2	0.0422	4.92	0.0100
Subject x Attentional Demand	46	0.0086		

Table 12

Subjective Attentional Demand One-Way ANOVA for EYENAV.

Source	df	MS	F	p
Attentional Demand	2	0.0033	0.35	0.7037
Subject x Attentional Demand	46	0.0094		

Table 13

Subjective Attentional Demand One-Way ANOVA for DRIVELINK.

Source	df	MS	F	p
Attentional Demand	2	0.0017	0.87	0.4254
Subject x Attentional Demand	46	0.0020		

Table 14

Subjective Attentional Demand One-Way ANOVA for AVECNTR.

Source	df	MS	F	p
Attentional Demand	2	0.4410	1.44	0.2444
Subject x Attentional Demand	46	0.3063		

Table 15

Subjective Attentional Demand One-Way ANOVA for AVEETAK.

Source	df	MS	F	p
Attentional Demand	2	1.1854	7.37	0.0013
Subject x Attentional Demand	46	0.1608		

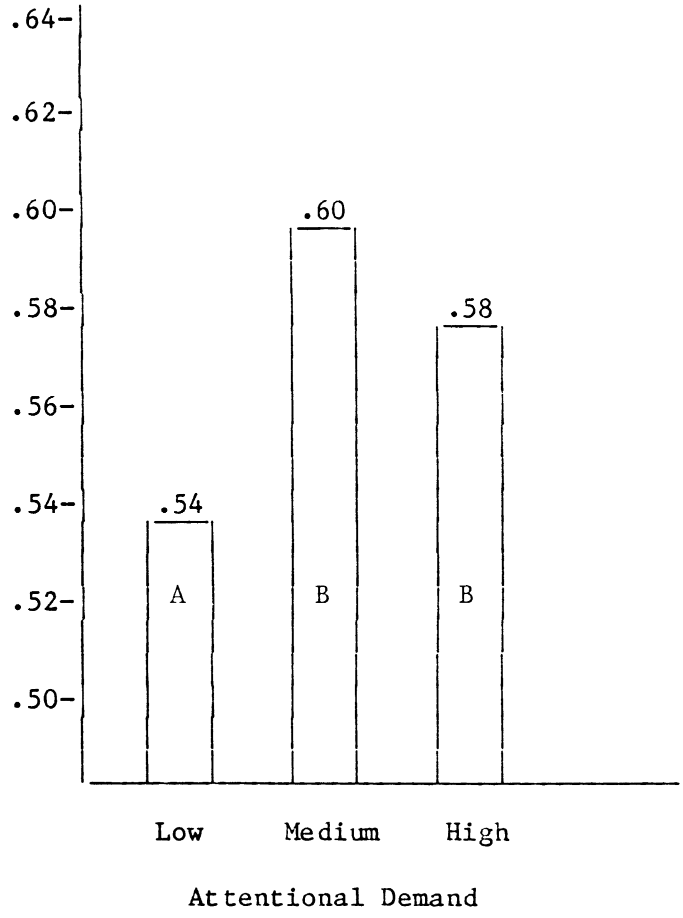

Figure 15. Probability of a Glance to Roadway Center, Mirrors, and Dashboard (EYEDRIVE) by Attention Demand for Subjective Data. (Groupings are based upon Newman-Keuls multiple comparisons. Different letters indicate attentional demand differences at the 95% confidence level).

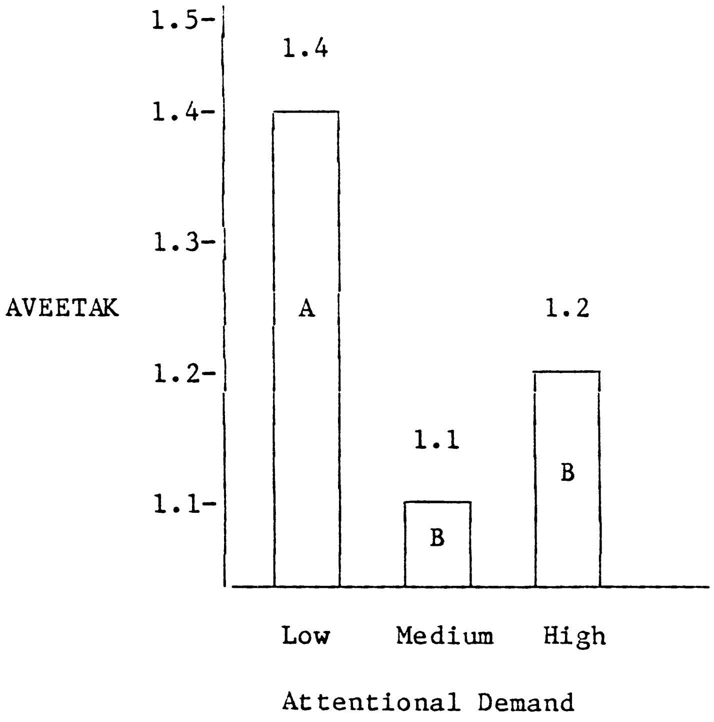

Figure 16. Average Glance Length to Etak (seconds) (AVEETAK) by Attentional Demand for Subjective Data. (Groupings are based upon Newman-Keuls multiple comparisons. Different letters indicate attentional demand differences at the 95% confidence level).

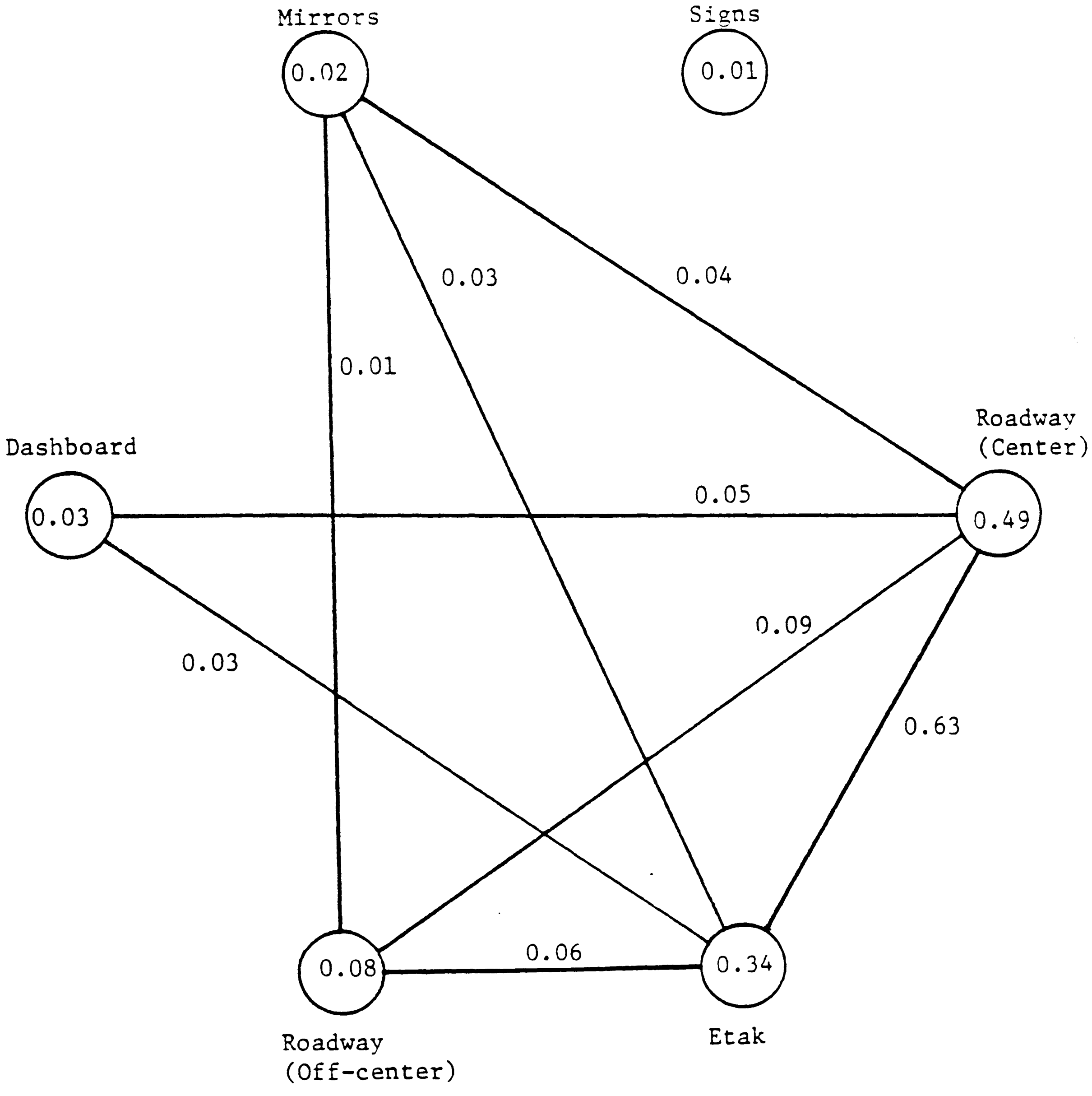

Figure 17. Glance and Link Value Probability Diagram for Low Subjective Attentional Demand.

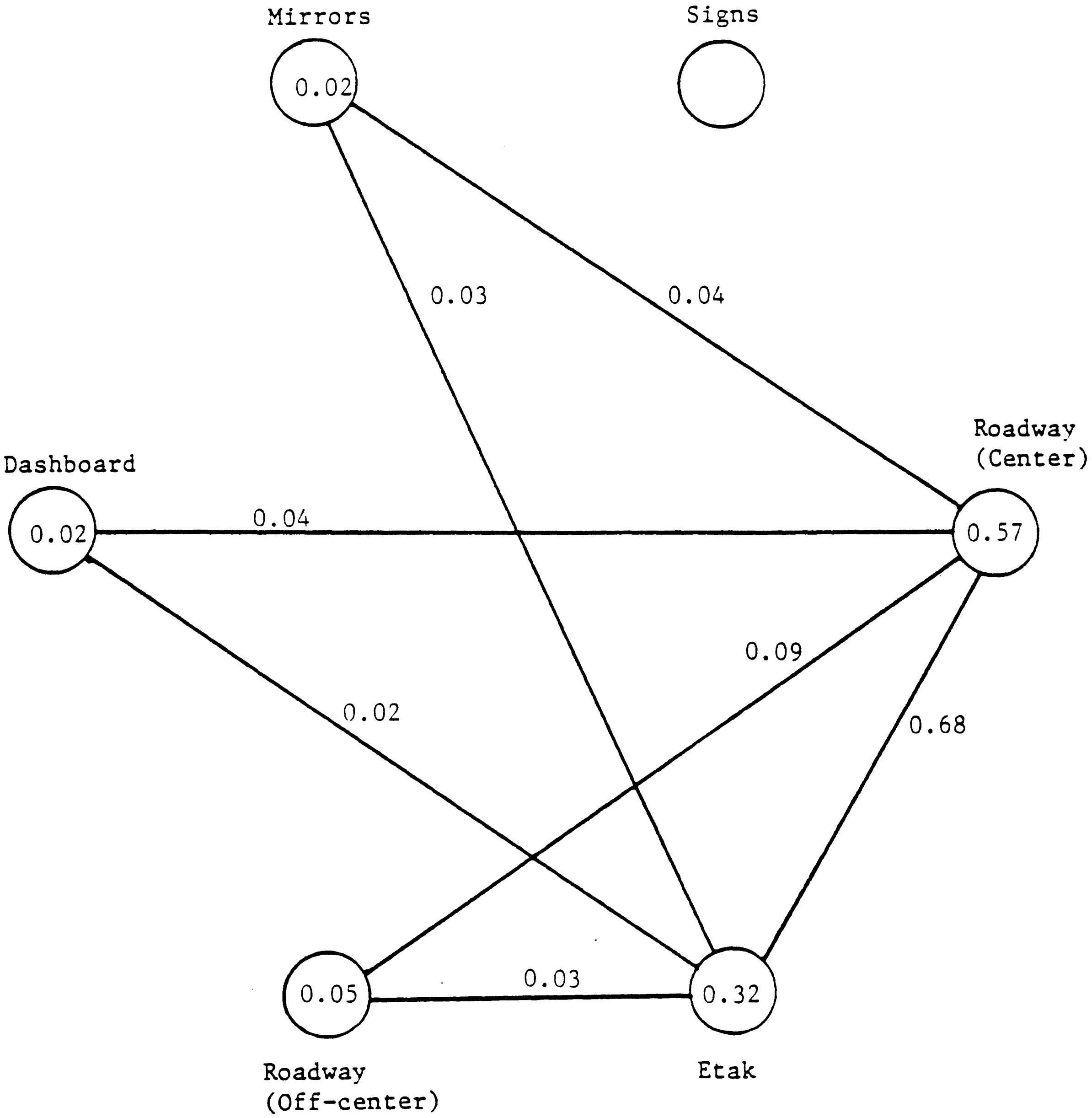

Figure 18. Glance and Link Value Probability Diagram for Medium Subjective Attentional Demand.

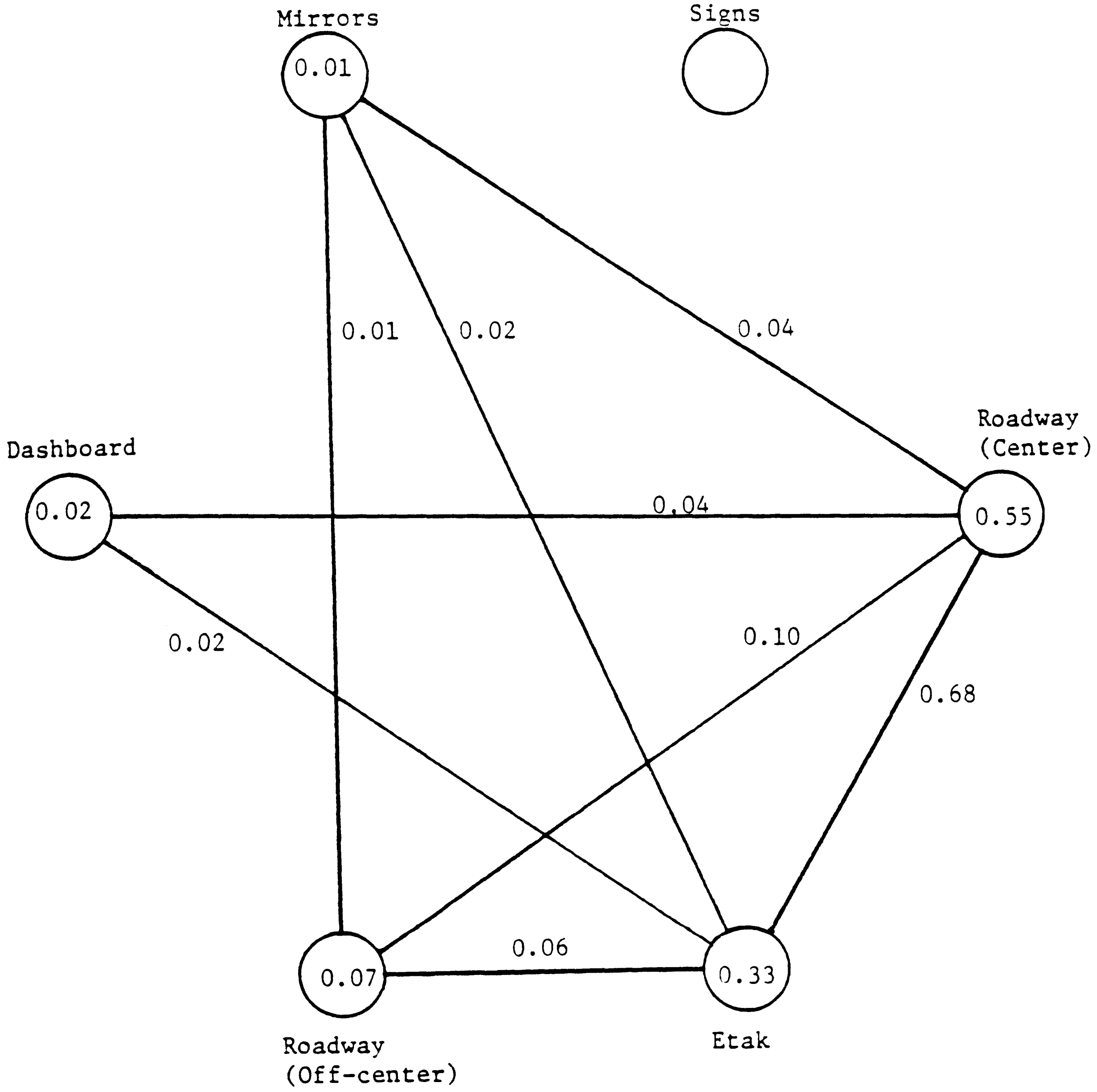

Figure 19. Glance and Link Value Probability Diagram for High Subjective Attentional Demand.

The multivariate analysis performed on the dependent measures using the subjective independent variable (Table 10) revealed that a main effect of gender was quite close to traditional levels of significance ($p = 0.0541$). Consequently, individual one-way ANOVAs were performed on the five dependent variables using gender as the independent variable. The results are presented in Tables 16 through 20. They show that only EYEDRIVE was significant at $p < .05$. The results are plotted in Figure 20, and they show that the females had a higher probability of glancing at roadway center, mirrors, and dash than did the males.

Table 16

Gender One-Way ANOVA for EYEDRIVE.

Source	df	MS	F	p
Gender	1	0.0685	5.63	0.0269
Subject/Gender	22	0.0122		

Table 17

Gender One-Way ANOVA for EYENAV.

Source	df	MS	F	p
Gender	1	0.0744	4.18	0.0530
Subject/Gender	22	0.0145		

Table 18

Gender One-Way ANOVA for DRIVELINK.

Source	*df*	*MS*	*F*	*p*
Gender	1	0.0101	2.53	0.1259
Subject/Gender	22	0.0040		

Table 19

Gender One-Way ANOVA for AVECNTR.

Source	df	MS	F	p
Gender	1	2.5301	3.67	0.0685
Subject/Gender	22	0.6894		

Table 20

Gender One-Way ANOVA for AVEETAK.

Source	*df*	*MS*	*F*	*p*
Gender	1	0.0053	0.01	0.9045
Subject/Gender	22	0.5300		

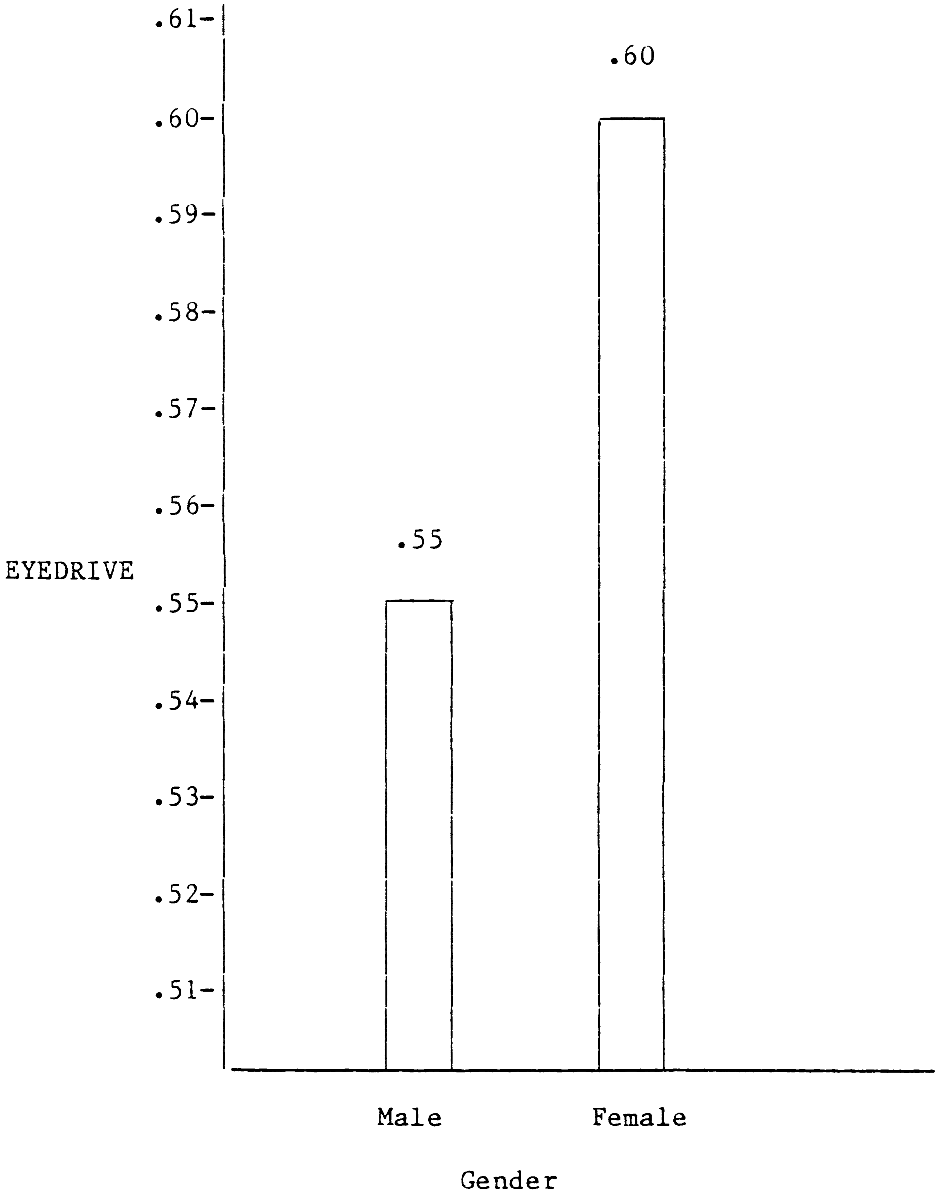

Figure 20. Probability of a Glance to Roadway Center, Mirrors, and Dashboard (EYEDRIVE) by Gender.

DISCUSSION - EXPERIMENT ONE

This experiment was undertaken to determine the degree and nature of eye glance changes, if any, associated with changes in anticipated driving task demand. Demand was defined primarily on the basis of the roadway itself. Both objective and subjective estimates were made.

Regression analyses conducted on the data showed that the glance probability to areas essential to the driving task (roadway center, mirrors, and dash), that is, EYEDRIVE, increased reliably with increases in both objectively and subjectively assessed attentional demand. These analyses also demonstrated that the glance probability to the navigator decreased reliably with both objectively and subjectively assessed attentional demand. These are important results, because they indicate that drivers adapted to increases in attentional demand by shifting their glance patterns toward the driving tasks and away from the navigator.

It should be noted (Table 1) that the slopes of the regression lines for EYEDRIVE and EYENAV are of approximately equal magnitude and opposite slope for the objective data set and also for the subjective data set. These results suggest that the incremental increases in visual attention to the driving task were obtained at the expense of an incremental decrease (of the same magnitude) in visual attention to the navigator.

In general, the regression analyses support the hypothesis that drivers properly adapt to higher roadway (anticipated) attentional demand. However, it is also clear from the scatter of the data around the regression lines that there are other relatively strong influences that were not accounted for in the model.

Of course there is no guarantee that anticipated attentional demand was accurately assessed. Since the demand assessments were used as a predictor variable, some of the variability in the data could be a result of inaccurate assessment.

It must also be recognized that driving per se is often a low visual attentional demand task. Under such circumstances, the driver's visual task is relatively unconstrained. This in turn may lead to variability or randomness in the scan pattern and glance times. Therefore, it is really not too surprising that there is a large amount of scatter about the regression lines.

The correlation analyses performed between the dependent and independent variables (Table 2) show relatively low level correlations. These correlations indicate that a relatively low proportion of variance was accounted for by the relationship between dependent and predictor variables of the experiment.

Table 3, which shows the correlations among the independent variables and components, indicates that correlations between the objective and subjective assessment independent variables were relatively high. Furthermore, the subjective ratings given by the preliminary group of drivers were most closely related to the component of sight distance in the objective assessment. For the overall objective assessment the same was true, with the objective rating most closely related to sight distance. However, it must be remembered that the objective rating included sight distance as a relatively heavily weighted value. Therefore, a portion of the correlation between the two variables is attributable to this systematic dependence. In general, the correlations in Table 3 give the impression that, at least in terms of consistency of the two measures (objective and subjective), the independent variables used in Experiment One did assess the attentional demand of the roadway to a reasonable degree.

It is also interesting to note that lane restriction was more highly correlated than curvature for both objective and subjective ratings ($p = .01$). This is especially interesting because curvature was weighted more heavily than lane restriction for the overall objective rating. Therefore, it is apparent that lane restriction accounts for a greater perceptual increase in attentional demand level than curvature.

When the data were separated into three groups (low, medium, and high) based on the two independent variables, the MANOVAs in both cases demonstrated a significant attentional demand main effect. These results indicate once again that the dependent variables in the experiment as a group change reliably as a function of the assessed objective and subjective demand.

Figure 11 and 16 show clearly that individual glances to the navigator are of longer duration under low attentional demand situations. This can be interpreted as indicating that drivers can afford to and do take a bit more time to gather information in low demand situations.

Figures 11 and 16 also indicate that the medium demand condition results in the shortest glance lengths to the navigator. Figure 16 does not show a significant difference between medium and high, however. It would seem that the high demand situation should have resulted in the shortest glance duration to the navigator. The experimenters observed, however, that under the high demand conditions, the roadways are often curved. As the driver nears the end of the curve, it is necessary to maintain the glance at the navigator to observe the reorientation (rotation) of the map. In other words, the driver takes a bit longer to observe the display because of the rapid changes taking place in the information presented.

Figure 10 appears to present a counterintuitive result. The average glance time to the roadway center is longer for the low demand situation than for the medium or high situation. It might seem that the opposite should have occurred. However, if the results of Figures 8 and 15 are taken into account, then the result in Figure 10 is more easily explainable. Figures 8 and 15 show that drivers increased the total proportion of time spent glancing at driving-related categories under medium and high load. This result was as expected and is similar to the results of the regression analysis. The results of Figure 10 then can be explained as an indication that drivers were sampling the forward roadway more often under medium and high conditions, but with shorter glances. Considering that the high demand segments of roadways were more complex, it is not surprising that drivers would shift fixation points within the forward field of view more often.

Before leaving Figures 8 and 15, it should be mentioned that these two figures are perhaps the most important in the analysis of variance results in supporting the adaptation of the driver's visual attention to increasing attentional demand. While the differences are small, they are reliable. (It should be noted that by coincidence the plots have the same rounded numerical values.)

The ANOVA shown in Figure 9 also provides results supporting the concept of adaptation. Interestingly, DRIVELINK decreases from low to medium and high demand. This result appears to indicate that drivers concentrate on the forward roadway view under medium and high demand, referring less often to the mirrors and dash. Such a strategy on the part of drivers is quite reasonable, since in most cases dash and mirror information can be neglected for short periods of time.

The link value and glance probability diagrams shown in Figures 12 through 14 and 17 through 19 show the strengths of associations in the scan patterns of the drivers. The most prominent changes are in glance probability to roadway center, as already discussed in the analysis of variance results. The other changes, such as the reduction in attention to the mirrors and dash, are also evident. However, in general, the diagrams do indicate that the magnitudes of the changes are relatively small.

The final result of Experiment One had to do with gender. Figure 20 indicates that females spent more time glancing at driving related glance areas than males. This behavior by female drivers is consistent with the results of Monty (1984) and Antin et al., (1986).

ADDITIONAL RESULTS AND DISCUSSION

The results in Experiment One indicate that attentional demand was objectively and subjectively quantified for this thesis. Due to these results, further analyses were conducted to address the issue of what effect the objective roadway ratings had on the perceived subjective attentional demand ratings.

Table 3 showed that when individual correlation analyses were conducted the physical measurement sight distance had the highest correlation (r=0.39) with the subjective rating. Other subjective rating correlation coefficients were roadway curvature (r=0.39), lane restrictions (r=0.43) and road width (r=0.29). An additional multiple correlation between subjective rating and the four roadway parameters was conducted and found to be significant with r equalling 0.73.

To gain a further understanding of the perception of attentional demand presumably caused by changes in roadway parameters, a multiple regression analysis was also conducted with subjective rating predicted by all combinations of roadway parameters. The results indicated that sight distance, curvature, and lane restriction provided the best subjective rating prediction information respectively. The three variables combined provided the best prediction model (adjusted r-squared = 0.52) with road width providing little additional prediction information.

The multiple regression analysis supports the findings of the correlation analyses.

These additional results add support to the previous findings discussed in this thesis. Those being that variations in sight distance provide the greatest perceived change in attentional demand of the roadway parameters investigated. The results also indicate that variations in roadway curvature and lane restriction change perceived attentional demand to some degree, but that road width has relatively little perceptual influence.

DEPENDENT VARIABLES - EXPERIMENT TWO

Experiment Two was undertaken to determine whether drivers would adapt to unanticipated driving demand by directing their visual attentional more toward the driving scene. As mentioned, the high demand was said to occur during "incidents". These were compared with normal, low, and high traffic situations.

The number of incidents that occurred per driver ranged from 1 to 13. Thus, unequal numbers occurred which, in turn, created the need for some additional analyses. Since it was recognized that unequal numbers would occur, the statistical analyses to be used could be planned in advance and as a result no unusual difficulties arose.

The number and types of incidents that occurred are listed in Appendix D. In all, 135 incidents were detected and analyzed. The dependent variables used in this second experiment were quite similar to those used in the first. However, there were certain differences. As already indicated, the interval over which measures were computed was the judged length of the incident and associated controlled conditions.

Incidents were detected by reviewing only the videotapes of the forward looking camera. This procedure was used so that the experimenters would not be biased in selecting an interval based on eye position. Once an incident was identified, the corresponding rearwardlooking camera videotape interval was analyzed for glance patterns. Similar-duration and roadway-situation segments were analyzed for the two control conditions.

Dependent Variable Definitions

Probability of a glance to the center roadway. To obtain this variable all glance lengths the driver made to the center roadway during the measurement interval were summed together and then divided by the total lengths of all glances made during the interval. The calculation was done separately for incidents, light traffic, and heavy traffic situations. (It should be noted that this measure is not the same as EYEDRIVE, because EYEDRIVE included glances to the mirrors and dash in the numerator).

Probability of a glance to the Etak. This variable was defined in the same way as in Experiment One. It was the fraction of total glance time spent looking at the Etak.

Number of glances made to the center roadway per unit time (seconds). Due to the varying lengths of glances for the seven glance categories, it was decided to distribute the time element more evenly. Thus, the number of eye glances to the center roadway was divided by the total time of the measurement interval. For example, a resulting value of .33 means that the subject made one glance every three seconds during the interval.

Number of glances to the Etak per unit time (seconds).

This variable is the counterpart of the number of glances to the center roadway per unit time (seconds). The total number of eye glances to the Etak was divided by the duration of the interval. Here again, if the resulting value was .33, the subject made one glance every three seconds.

Mean glance time to the center roadway (seconds). To obtain this variable from the raw data, the different lengths of time per glance to the center roadway over the measurement interval were averaged.

Mean glance time to the Etak. This variable is the counterpart of the above variable. The glance times to the Etak were averaged over the measurement interval.

RESULTS - EXPERIMENT TWO

Multivariate Analyses of Variance (MANOVA)

Because the number of incidents varied with the subject, two multivariate analyses were performed. For the first of these, each subject's data were averaged individually. If, for example, a given subject experienced three incidents, then the measures for the three incidents were averaged. (The three sets of measures for the two control conditions were also averaged.) This procedure produced a single value of each measure for each subject for incident, for low traffic, and for high traffic. The resulting MANOVA, which is termed "by subject," is presented in Table 21. The results indicate that traffic type and age were statistically significant. Neither gender nor any of the interactions was significant.

The MANOVA in Table 21 demonstrates a traffic main effect based on averages per subject. However, such an analysis, if used by itself, could be criticized because the individual incidents are unequally weighted in the analysis. To address this potential criticism, a second one-way MANOVA was performed on the data. In this case the measures from each incident and control condition were treated as an event. In other words, each set of three measures was treated without regard to the subject from which it came. This produced equal weighing in the analysis for each incident. The results of this MANOVA are

Table 21

MANOVA on Data by Subject.

Source	df	*F*	*p*
Traffic Type (T)	2	4.58	0.0001
Age (A)	2	2.15	0.0480
Gender (G)	1	0.78	0.6146
T x A	4	1.46	0.0860
T x G	2	1.04	0.4276
A x G	2	1.83	0.0939
T x A x G	4	0.87	0.6537
Subject/A,G	18		
T x Subject/A,G	36		

presented in Table 22. Traffic type was again found to be significant. This supports the argument that averaging by subject did not significantly bias the outcome of the analysis.

Analyses of Variance (ANOVAs)

Two-way ANOVAs were conducted for each dependent variable to determine where the differences were for the independent variables of age and traffic type. As reported above, only age and traffic type main effects were found significant in the MANOVA.

The ANOVA conducted on the probabilities of a glance to the center roadway and to the Etak found the traffic type main effect to be the only factor significant at $p = 0.05$. The results are shown in Tables 23 and 24.

The ANOVA performed on the mean glance time to the center roadway (Table 25) revealed both traffic type and age main effects to be significant, as well as the interaction of traffic type and age. Because the interaction was not significant in the MANOVA it will not be discussed further.

The results for the mean glance time to the Etak ANOVA are shown in Table 26 and exhibit no significant effects. Tables 27 and 28 are the ANOVAs for the number of glances to the center roadway per unit time and the number of glances to the Etak per unit time, respectively. The number of glances to the center roadway results found

Table 22

One-Way MANOVA on Data by Event Set.

Source	df	F	p
Traffic Type (T)	2	6.19	0.0001
Event set x T	256		

Table 23

Two-Way ANOVA on Probability of a Glance to Roadway Center by Subject.

Source	df	MS	F	p
Traffic Type (T)	2	0.4850	7.35	0.0018
Age (A)	2	0.0456	0.60	0.5591
T x A	4	0.1635	2.48	0.0585
Subject/A	21	0.0763		
T x Subject/A	42	0.0659		

Table 24

Two-Way ANOVA on Probability of a Glance to Etak by Subject.

Source	df	MS	F	p
Traffic Type (T)	2	0.4038	5.86	0.0057
Age (A)	2	0.0614	0.79	0.4686
T x A	4	0.1110	1.61	0.1897
Subject/A	21	0.0780		
T x Subject/A	42	0.0690		

Table 25

Two-Way ANOVA on Mean Glance Time to Roadway Center by Subject.

Source	df	MS	F	p
Traffic Type (T)	2	105.3050	25.30	0.0001
Age (A)	2	35.1579	3.90	0.0362
T x A	4	22.3824	5.38	0.0014
Subject/A	21	9.0086		
T x Subject/A	42	4.1617		

Table 26

Two-Way ANOVA on Mean Glance Time to Etak by Subject.

Source	df	MS	F	p
Traffic Type (T)	2	2.2065	1.61	0.2116
Age (A)	2	0.6369	0.37	0.6953
T x A	4	2.3345	1.71	0.1668
Subject/A	21	1.7220		
T x Subject/A	42	1.3687		

Table 27

Two-Way ANOVA on Number of Glances to Roadway Center per Unit Time (Seconds) by Subject.

Source	*df*	*MS*	*F*	*p*
Traffic Type (T)	2	0.9460	12.92	0.0001
Age (A)	2	0.5739	4.00	0.0338
T x A	4	0.0341	0.47	0.7610
Subject/A	21	0.1436		
T x Subject/A	42	0.0732		

Table 28

Two-Way ANOVA on Number of Glances to Etak per Unit Time (Seconds) by Subject.

Source	df	MS	F	p
Traffic Type (T)	2	0.4313	12.28	0.0001
Age (A)	2	0.1498	2.11	0.1468
T x A	4	0.0555	1.58	0.1970
Subject/A	21	0.0711		
T x Subject/A	42	0.0351		

traffic type and age main effects to be significant. Only traffic type was found to be significant for the number of glances to the Etak per unit time, however.

Post-Hoc (Newman-Keuls) Comparisons

Newman-Keuls comparison tests were conducted for the dependent measures for which main effects were found to be significant. For the age variable, the number of incidents was not equal for every subject, therefore, subjects with a larger number of incidents created a more reliable sample of their actual response during an incident and associated traffic conditions.

The Newman-Keuls test performed on the dependent variable probability of a glance to the center roadway for traffic type is shown in Figure 21. Light traffic was significantly different from the heavy traffic and incident conditions. However, no difference was found between heavy traffic and incident. Subjects had a significantly lower probability of glancing toward the center roadway during light traffic compared to the probabilities during heavy traffic and incident situations.

The analysis for traffic type conducted on the probability of a glance to the Etak found light and heavy traffic to be significantly different from the incident situation. As shown in Figure 22, the probability of a glance to the Etak was lower during an incident.

Figure 23 reveals the differences by traffic type for

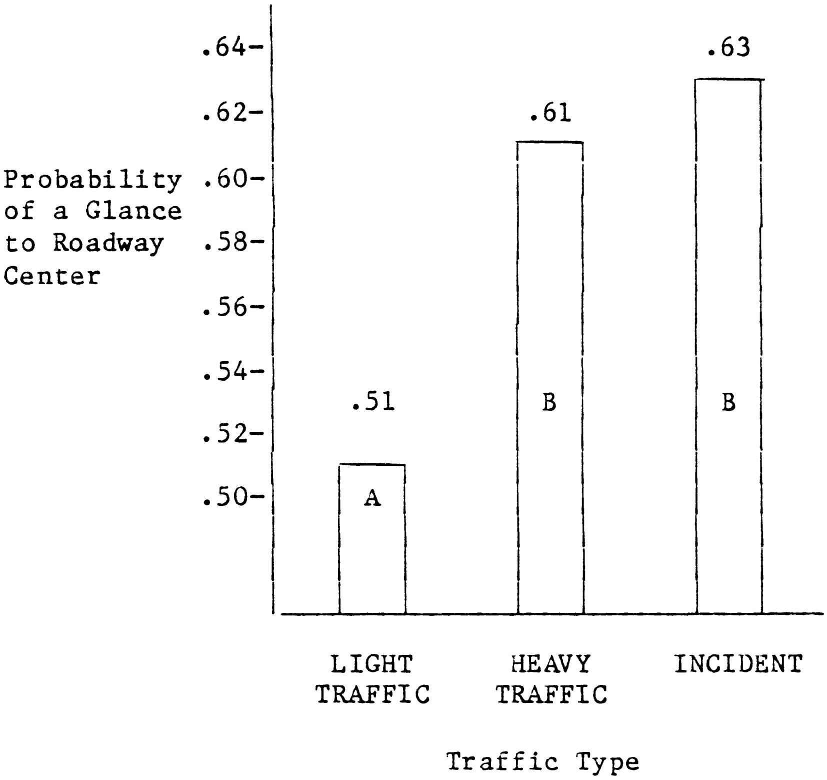

Figure 21. Probability of a Glance to Roadway Center for Traffic Type by Subject. (Groupings are based upon Newman-Keuls multiple comparisons. Different letters indicate Traffic type differences at the 95% confidence level).

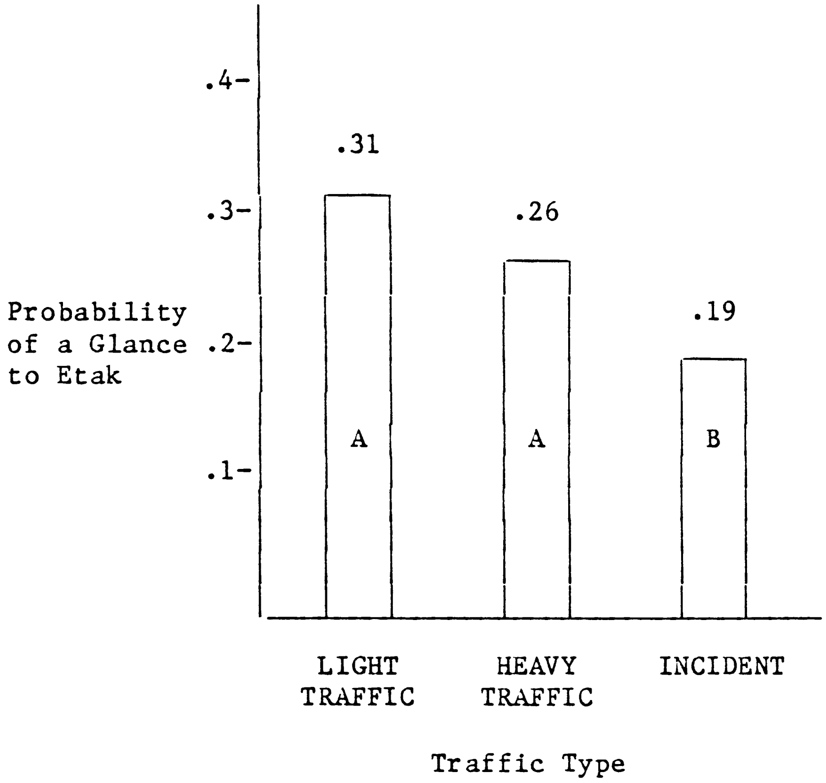

Figure 22. Probability of an Etak Glance for Traffic Type by Subject. (Groupings are based upon Newman-Keuls multiple comparisons. Different letters indicate Traffic type differences at the 95% confidence level).

the Newman-Keuls test conducted on the mean glance time to the center roadway. Significant differences were found among all three levels of traffic type: light traffic, heavy traffic, and incident. Light traffic had the shortest mean glance time followed by heavy traffic and then followed by incident.

The Newman-Keuls test for age (Figure 24) performed on the same dependent variable (mean glance time to roadway center) demonstrated a significant difference between the 18-30 age group, which had the shortest mean glance time to the center roadway, and the 31-44 and 45+ age groups. No difference was found between the 31-44 and 45+ age groups.

The Newman-Keuls test for age performed on number of glances to roadway center indicated that the 18-30 age group had a significantly higher number of glances to the center roadway (Figure 25). The 31-44 and 45+ age groups were not signficantly different from each other.

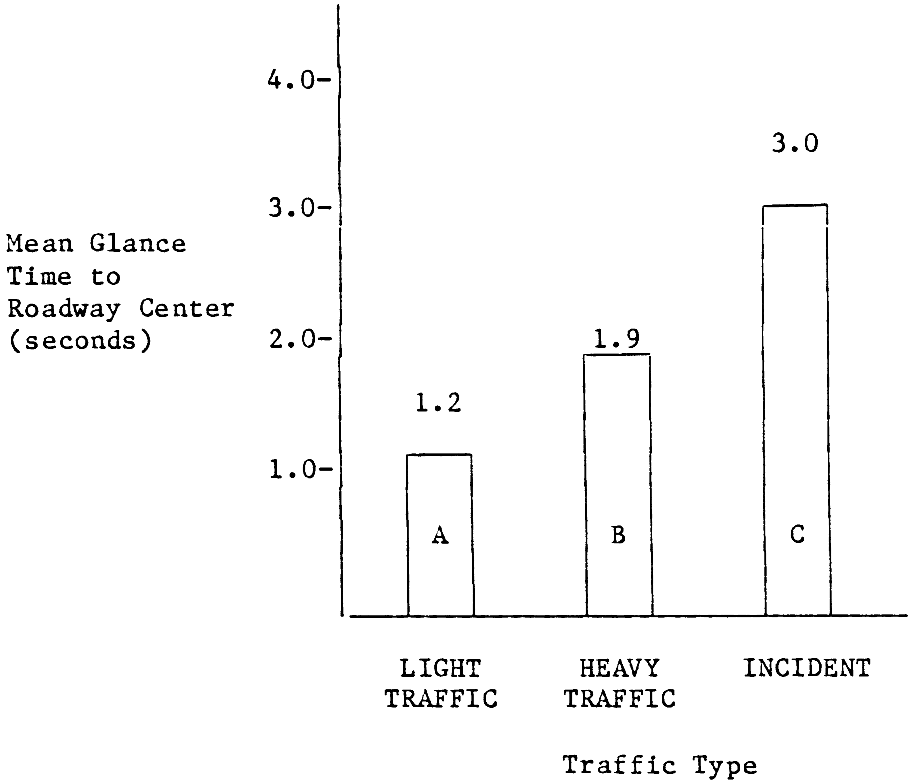

Figure 23. Mean Glance Time to Roadway Center (seconds) for Traffic Type by Subject. (Groupings are based upon Newman-Keuls multiple comparisons. Different letters indicate Traffic type differences at the 95% confidence level).

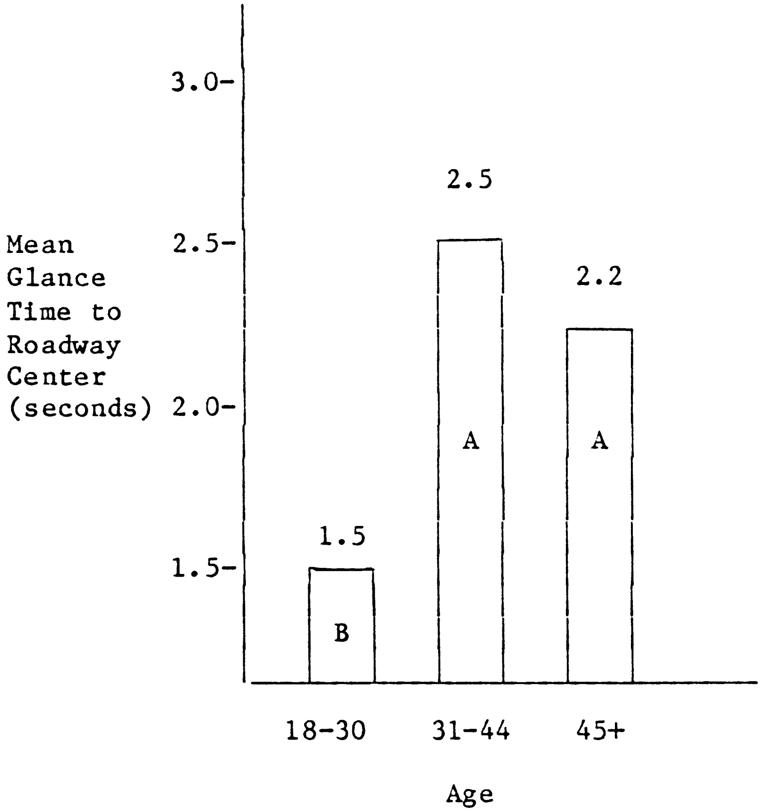

Figure 24. Mean Glance time to Roadway Center (seconds) for Age by Subject. (Groupings are based upon Newman-Keuls multiple comparisons. Different letters indicate age differences at the 95% confidence level).

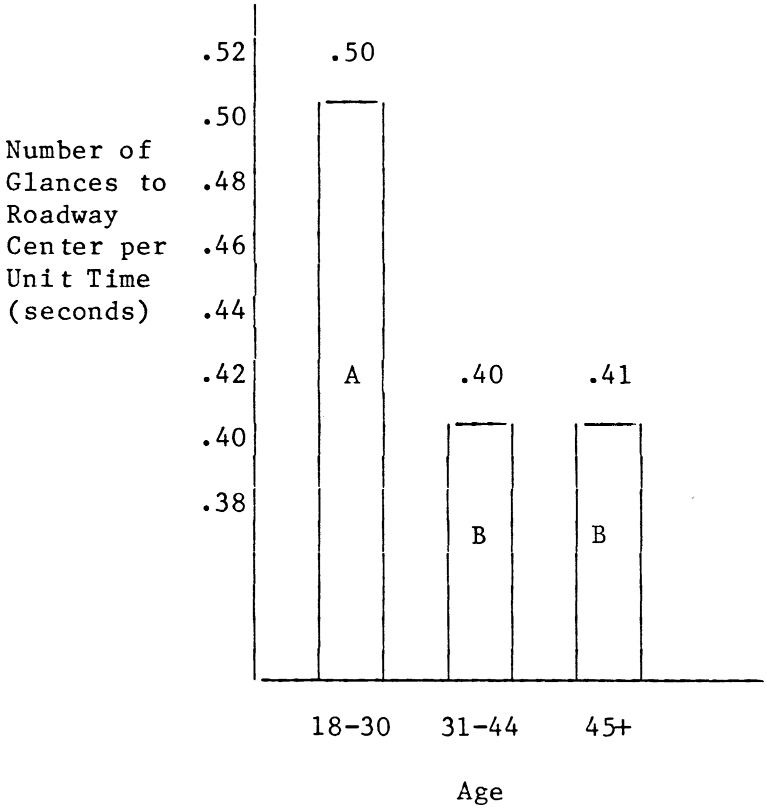

Figure 25. Number of Glances to Roadway Center per unit time (seconds) for age by subject. (Groupings are based upon Newman-Keuls multiple comparisons. Different letters indicate age type differences at the 95% confidence level).

DISCUSSION - EXPERIMENT TWO

The main purpose of this experiment was to determine the nature and degree to which drivers would adapt their visual attention to increases in unanticipated driving attentional demand. To make such a determination, incidents as well as control conditions in low traffic and in high traffic were examined.

A multivariate analysis of variance was performed on the resulting data, indicating reliable changes in the group of measures as a function of traffic type (that is, incident, low traffic, and high traffic) and as a function of age group (18 to 30, 31 to 44, and 45 or more). Because unequal numbers of incidents occurred per subject, an additional one-way MANOVA was performed by event, and it also demonstrated a significant traffic type effect. This latter result suggests that analysis by subject did not seriously bias the traffic-type effect.

The subsequent analyses of variance and post-hoc tests showed that a subset of the measures was responsible for the domain of significance in the MANOVAs. These measures are discussed individually.

Figure 22 shows that probability of a glance to roadway center was higher for both heavy traffic and incidents than it was for light traffic. This result suggests that drivers pay more attention to the driving situation in heavy traffic and during the occurrence of an incident. It represents major evidence to support the hypothesis that drivers do adapt to driving task demands while driving. However, the results in Figure 21 do not support the hypothesis that drivers deal differently with normal heavy traffic than they do with an incident. Apparently, heavy traffic by itself is sufficient to induce a shift in visual attention to the forward view.

Figure 22 demonstrates that clear-cut result that visual attention paid to the navigator decreases when an incident is in progress. This result demonstrates appropriate adaption on the part of the driver.

Figure 22 also suggests that the mean attentional values decrease from light to heavy traffic, although this difference is not statistically significant. Overall, Figure 22 supports the hypothesis that the driver reduces visual attention to the navigator as appropriate for the driving situation, when an unanticipated high demand situation occurs.

Figure 23 also demonstrates support for the hypothesis of appropriate adaptation. In particular, glance duration to roadway center is significantly longer during the occurrence of an incident than in regular traffic. Additionally, glance duration is longer in heavy traffic than in light traffic. These results are best interpreted in terms of level and unpredictability. As long as there is a likelihood that another vehicle may come into conflict with the subject's vehicle, the subject must watch that vehicle carefully. An incident, as defined earlier in this thesis is, by definition, such a situation. Thus, longer glance time should occur if the subject is adapting properly. The subject must monitor the other vehicle because of the unpredictability of its path.

Likewise, the total amount of unpredictability is greater in heavy traffic than in light traffic. Therefore, subjects are more likely to have to monitor the situation in heavy traffic even though a specific incident is not in progress. The results of Figure 23 are important because they indicate that the drivers did appropriately adjust glance duration to the driving situation even though they were navigating.

For the age main effect, Figure 24 shows that while navigating, younger subjects had shorter glance durations to the roadway center than did the mid-age and older age groups. Figure 25 found that younger subjects also had a higher number of glances to the center roadway. These results, while not identical to those found in one of the 1986 studies (Dingus et al., 1986), are nevertheless consistent with those studies. In the previous study, an over-fifty age group exhibited longer glance durations and more numerous errors. The present experiment shows the longer glance times as well, but includes both the mid- and older-age subjects.

CONCLUSIONS

The regression analyses conducted in Experiment One demonstrated that the drivers adapted to high attentional demand by increasing the proportion of time spent looking at driving-relating visual areas while decreasing the proportion of time spent observing the Etak by about the same amount. This result demonstrates a shift in visual attention toward driving and away from the Etak. However, there is a large amount of scatter about the regression lines, especially for the objective assessment of roadway attentional demand, indicating that some of the variablility in the data could be a result of inaccurate assessment.

The analysis of variance and post-hoc tests performed in Experiment One also support the adaptation hypothesis and they shed more light on the nature of the changes in scanning behavior for high anticipated attentional demand in driving. The following definitive statements can be made about adaptation as a result of the findings:

* Drivers narrowed their scan and concentrated more on roadway center as anticipated demand increased.
* Visual glances to the roadway center increased in frequency and decreased in duration as anticipated demand increased.
* Visual glances to the Etak decreased in

duration as anticipated demand increased. However, under high demand, visual glances to the Etak increased again slightly. This is believed to be due to the need on the part of drivers to re-orient themselves to the turning map late in the turns.

Experiment Two, which dealt with unanticipated attentional demand, also supports an adaptation hypothesis. MANOVAs performed by subject and by event indicated reliable differences as a function of "traffic," that is, the independent variable involving low traffic and high traffic non-incidents as well as incidents. Subsequent examination of the specific dependent measures demonstrated the following:

* Drivers increased their proportion of visual time spent on roadway center for high traffic and incident situations, as compared with low traffic situations.
* Drivers decreased their proportion of visual time spent on the Etak for incident situations, as compared with all non-incident situations.
* Drivers increased their glance durations to roadway center for incidents as compared to both heavy and light traffic non-incidents.
* Drivers increased their glance durations to

roadway center for heavy traffic non-incidents compared with light traffic non-incidents.

These changes are in the correct direction for proper adaptation on the part of the driver.

The results of the two experiments can be combined to provide a model of the adaptation process, as follows:

- For increases in both anticipated and unanticipated driving demand, drivers increase the proportion of time spent on the forward central view and decrease the proportion of time spent observing the navigator.
- However, increased _anticipated_ (roadway) demands result in an _increased_ visual sampling rate by the driver. This higher sampling rate is believed to be a result of the need for increased attention to the roadway while at the same time having to reorient with the rotating map of the navigator (due to turning). In other words, driving task demand increases appreciably while the navigation task demand increases somewhat. The driver handles the combination by an increase in sampling rate.
- For increased _unanticipated_ (traffic and

incident) demands, the visual sampling rate decreases and drivers concentrate on the forward view with longer glances. Here, the traffic situation takes precedence. Furthermore, there is generally no need to reorient with the navigator. Thus, navigator demands do not increase and in fact are postponed.

These results suggest rational adaptive behavior on the part of the driver and indicate that drivers are able to adapt as needed to changing demands in driving.

The subjects used in this experiment were "practiced novices," and would be typical of drivers who had owned and operated their navigators for perhaps a few days to a few weeks. The fact that they could adapt to high roadway and traffic demand situations suggests that more experienced users certainly could do so also. More experienced users would probably require less glance time to extract information from the Etak and would have had more experience in reorienting during turns. Thus, more of their visual processing time could be devoted to driving per se.

Experiment Two demonstrated certain age effects as did one of the previous studies (Dingus et al., 1986). The results obtained from the two studies are largely in agreement and indicate a somewhat more conservative approach on the part of the older driver.

REFERENCES

Antin, J. F., Dingus, T. A., Hulse, M. C., and Wierwille, W. W. (1986). Human factors test and evaluation of an automobile moving-map navigation system--Part II: Methodology issues - effectiveness, efficiency, and strategy. Vehicle Analysis and Simulation Laboratory, Virginia Polytechnic Institute and State University. Blacksburg, Virginia. IEOR Department Report No. 86-03.

Bhise, V. D., Forbes, L. M. and Farber, E. I. (1986). Driver behavioral data and considerations in evaluating in-vehicle controls and displays. Paper presented at the Transportation Research Board 65th Annual Meeting, Washington, D.C.

Cohen, A. S. and Studach, H. (1977). Eye movements while driving cars around curves. Perceptual and Motor Skills, 44, 683-689.

Dingus, T. A., Antin J. F., Hulse, M. C., and Wierwille, W. W. (1986). Human factors test and evaluation of an automobile moving-map navigation system--Part I: Attentional demand requirements. Vehicle Analysis and Simulation Laboratory, Virginia Polytechnic Institute and State University, Blacksburg, Virginia. IEOR Department Report No. 86-03.

ETAK Navigator Operating Instructions (1985). Etak, Inc., Menlo Park, CA. (a).

ETAK Navigator Owner's Guide (1985). Etak Inc., Menlo Park, CA. (b).

Farber, E., and Gallagher, V., (1972). Attentional demand as a measure of the influence of visibility conditions on driving task difficulty. Highway Research Record, 414, 1-5.

Fowkes, M. (1984). Presenting information to the driver. Display Technology and Applications, 5, 215-223.

Godthelp, H. (1986). Vehicle control during curve driving. Human Factors, 28, 211-221.

Jurgen, R. K. (1982). Drivers get more options in 1983. IEEE Spectrum, November, 30-36.

Lopez, L. A. (1982). Display technology. Society of Automotive Engineers Technical Paper Series, SAE paper no. 820914, 191-197.

Monty, R. W. (1984). Eye movements and driver performance with electronic automotive displays. Unpublished ster's thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Mortimer, R. G. and Jorgenson, C. M. (1972). Eye fixations of drivers as affected by highway and traffic characteristics and moderate doses of alcohol. Proceedings of the Human Factors Society 16th Annual Meeting, 86-92.

Mourant, R. R., Herman, M., and Moussa-Hamouda, E. (1980). Direct looks and control location in automobiles. Human Factors, 22, 417-425.

Mourant, R. R. and Rockwell, T. H. (1970). Mapping eye-movement patterns to the visual scene in driving: An exploratory study. Human Factors, 12, 81-87.

Perel, M. (1974). Controls and display: Problems, progress, and priorities. Society of Automotive Engineers, Inc., SAE paper no. 740994.

Rackoff, N. J. (1975). An investigation of age-related changes in drivers' visual search patterns and driving performance and the relation to tests of basic functional capacities. In Proceedings of the Human Factors Society 19th Annual Meeting, 285-288.

Rockwell, T. (1972). Skills, Judgement, andInformation Acquisition in Driving. In: Forbes, T. W. Human Factors in highway traffic safety research. Wiley Interscience, New York.

Senders, J. W., Kristofferson, A. B., Levinson, W., Dietrich, C. W. and Ward, J. L. (1966). An investigation of driver information processing. U.S. Department of Commerce Report No. 1335.

Sender, J. W., Kristofferson, A., B., Levinson, W., Dietrich, C. W. and Ward, J. L. (1967). The attentional demand of automobile driving. (Highway Research Record, No. 195, pp.15-33). Washington, D.C.: Transportation Research Board, National Academy of Science.

Tagami, K., Takahashi, T., and Takahashi, F. (1983). "Electro Gyro-Cater" new inertial navigation system for use in automobiles. Society of Automotive

Engineers Transactions, SAE paper no. *830659*.

Totani, S., Kato, T., and Muramoto, K. (1983). Automotive navigation system. *Motor vehicle technology: Progress and harmony*. SAE of Japan, Inc.

Young, L. R. and Sheena, D. (1975). Methods and designs: Survey of eye movement recording methods. *Behavior Research Methods and Instrumentation*, *7*, 397-429.

Yun, J. S. (1985). Automotive convenience products: Trends and prospects. *Automotive electronic displays and information systems*, SAE paper no. *850310*.

APPENDIX A

INSTRUCTIONS AND PROCEDURE FOR THE COLLECTION OF THE SUBJECTIVE RATINGS

INSTRUCTIONS

For this study you will be asked to drive along a preselected route and call out numbers pertaining to a subjective rating scale. The subjective rating scale is based on different levels of visual attentional demand. Visual attentional demand is defined as the ability to take your eyes off the roadway at a certain point in time, although you probably will not do so. The front seat experimenter will say "Now" at points along the roadway where you are to give a rating.

Procedure

1. You will be shown a map which contains the route you will be driving. You are not expected to memorize this route, just to become familiar with the area you will be driving. You will drive the roadway one time for practice and again for data gathering. During the runs, the back seat experimenter will tell you where you should turn.
2. You will be shown a sheet of paper which contains a subjective rating scale. This scale goes from "1" (lowest level of visual attentional demand) to "9" (highest level of attentional demand). You should study this scale until you know what the different

numbers on the scale mean in terms of the visual attentional demand level. An experimenter will review the subjective scale with you and answer any questions you may have.

3. An experimenter will discuss what you should consider when giving your response. The items are listed below.
4. You will be driven to the beginning of the route and asked if you have any further questions. Once any questions have been answered, you will begin to drive the route.

While driving the route the front seat experimenter will say "now" at certain points along the roadway. At each point, you will be expected to say a number quickly (from one to nine), based upon the subjective rating scale, that you feel corresponds to the visual attentional demand at that point on the roadway. It might be helpful to constantly be thinking of a number during the route so you can respond quickly.

Items you should think about when responding with a number are:

1. Ability to look away. Even though you are not looking away from the roadway, could be possibly look away, and if so, for how long?
2. The type of roadway you are driving. For example, is the roadway narrow and curved, or wide and straight.
3. The possibility of unanticipated traffic. For

example, if you are driving over a hill and cannot see the future roadway, you should consider the possibility of cars coming in the other direction, as well as hidden curves when giving your subjective rating for that piece of roadway.

4. Consider intersections and the possibility of having to interact with other vehicles, even though they may not be present.

It is very important that you understand you are assessing the visual attentional demand of the roadway you are looking at through the windshield. When the experimenter says "Now" your response should be based on what you see outside at that point in time. Be sure to consider the different factors discussed above when giving your response, and respond quickly.

APPENDIX B

SUBJECTIVE RATING SCALE

RATING SCALE

VISUAL ATTENTIONAL DEMAND RATING	**ABILITY TO LOOK AWAY FROM ROADWAY**
1	Can look away from roadway for long periods, possibly 4 secs. or more. (Frequent and long duration looks away are possible.)
2	
3	
4	
5	Can look away from roadway for intervals of 1 to 1.5 secs., but not longer. (Looks away must be followed by quick return to roadway.)
6	
7	
8	
9	Cannot look away from roadway for even a brief glance. (Total visual attention required by roadway.)

APPENDIX C

SUBJECT'S INTRODUCTION AND INFORMED CONSENT FORM

Introduction to the Navigation Study

The purpose of the study is to evaluate driver performance using an in-car moving-map display, the Etak Navigator, hereby referred to as the navigator. This study is being conducted by the Vehicle Analysis and Simulation 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 Melissa Hulse and Terence Fischer who are M.S. candidates 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 be asked to navigate unfamiliar routes in the local area. Two trained experimenters will ride in the car with you throughout 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 must treat the driving task as the primary task and perform navigator tasks only when it is safe to do so. 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 two sessions:

Session I

This session will consist of all preliminaries, including training. You have already been given introductory material. Thereafter, you will read the informed consent form. Assuming that you sign this form, we will give you a vision test and a simple hearing test. We will also ask to see your driver's license. In addition, we will ask you to fill out a brief medical questionnaire and a brief driving experience questionnaire. If you pass the tests, we will begin your training.

You will first study the owner's manual for the navigator. Thereafter, you will be taken to the research vehicle so that you can learn how to use the navigator and also become familiar with the car's normal driving instrumentation. While the vehicle is parked, you will be shown how the navigator works and you will practice with it. Thereafter, you will drive with the navigator and continue to learn how to use it. The driving will continue until you are thoroughly familiar with the use of the navigator.

The entire length of the first session is expected to be approximately two and one-half hours. However, because training varies with the individual, it is possible that your session may be somewhat shorter or longer.

Session II

This session will begin with one more practice run involving driving the car and using the navigator. Thereafter, your data runs will begin. In these runs, you will use the navigator to drive from given starting points, along unfamiliar routes, to given destinations. Although it is important to navigate the routes as quickly as possible, it is also important to minimize errors(e.g. wrong or missed turns). Therefore, if necessary, you may stop the vehicle at any safe and legal place to more accurately navigate the route.

This second session is also expected to take about two and one-half hours. Again, however, the time may vary.

Upon completion of the data gathering runs, you will be driven back to Virginia Tech. You will be paid $5.00/hr for the total time that you have spent.

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. 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 1, 1987; you may feel free to discuss the study with anyone after than date.

It is possible that at times driving while using the navigator may seem difficult, and you may feel stressed and frustrated. Your performance and feelings reflect the difficulty of the driving 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.

Participant's Informed Consent

I. 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.

II. 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, as well as on straight and curved roadways,

B. The slight additional risks of an accident that might possibly occur while reading the navigator. Past research indicates that this risk is minimal.

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. Each of the two sessions is expected to last approximately two and one-half hours. (There will be rest breaks, however.)

B. Wearing the microphone might become a bit uncomfortable towards the end of the study.

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

IV. While there are no direct benefits to you from this research (other than payment), you may find using the navigator to get to a destination interesting. 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.

V. 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 low blood pressure, hearing conditions, 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.

VI. 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 Institutional Review Board, if you have questions or concerns about this experiment. His phone number is (703) 961-5284.

VII. 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.

VIII. 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:________________________

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

Signature:________________________

Date:________________________

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

Signature:_________________________

Date:_________________________

APPENDIX D

DESCRIPTION OF INCIDENTS

1. The most common type (25%) of occurrence involves traffic at cross street intersections. This situation involves a car entering the intersection from a side street as the subject driver approaches the intersection. The movement of the second vehicle required the subject to allocate attention to the vehicle. This situation would not allow the subject to view the Etak navigator. Only a small percentage of these involved the cross traffic actually moving into or across the subject driver's lane.
2. Impending turns across the subject driver's lane was another common occurrence (20%). In this situation a car traveling in the opposite direction would slow and indicate a turn across the subject driver's lane into a parking lot, driveway, or small side street. Turns at major intersections which involved stop lights and incidents where the opposing car was previously stopped were not included. This situation would induce an apprehensive state in the driver in which he or she would not be able to view the Etak safely.
3. In multiple-lane traffic situations an occurrence was caused when a car would switch lanes in front of the subject driver's car. This could be from a turn lane into the driver's lane or from an adjacent lane into

the driver's lane. This movement would require attention of the driver due to the immediate reduction in following distance. Sometimes this would require a reduction in speed to regain a safe following distance.

4. During the in-city driving a few occurrences were caused by pedestrian traffic. Generally this involved the pedestrian suddenly leaving the sidewalk and moving to the lane edge (usually around or between parked cars) in front of the subject driver. This category also included situations where the driver of a parked car suddenly egressed the car onto the lane edge.

Table 29

Type and Number of Incidents (Occurrences)

		#of Occ
1.	Cross traffic approach intersection when the subject driver approaches intersection.	41
2.	Opposing traffic slows and indicates turn across subject driver's lane.	22
3.	Preceding car slows suddenly requiring attention of subject driver.	26
4.	Car pulls out in front of subject driver causing driver to decrease speed.	13
5.	Traffic in adjacent lane moves into subject driver's lane. (Same direction)	7
6.	Avoidance of parking car.	7
7.	Pedestrian approaches roadway edge.	5
8.	Driver exiting from parked car.	3
9.	Car pulls across lane to proceed in opposing direction.	3
10.	Person crossing roadway.	3
11.	Car moves from adjacent lane into subject driver's lane only to slow and turn. (One left turn; one right turn)	2
12.	Bicyclist on roadway.	1
13.	Trash truck making pickup pulls into lane.	1
14.	Opposing traffic turns left across roadway.	1

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