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Drivers' Visual Attention to In-Vehicle Displays: Effects of Display Location and Road Type

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16. Abstract

The purpose of this report is to describe two experiments concerning the attentional demand of in-vehicle displays while driving on public roads. In the first experiment, 10 younger and 12 older drivers participated on an expressway, a rural road, and a suburban street. Their glances to the instrument cluster, the center console, and a head-up display were recorded by an eye-mark recorder. They were instructed to look at the targets as much as safely possible. In the second experiment, another 8 younger drivers' visual behavior relative to the same targets, on urban streets, was recorded by a small video camera. Vehicle operation data (speed, steering-wheel angle, and throttle-opening ratio) were recorded in both experiments.

The results of both experiments showed that drivers' glance behavior relative to in-vehicle displays was affected by the display location and the road type. The effect of the road type was more significant than the display location. While driving on the three road types in the first experiment, the drivers' median glance durations were: 0.79 sec to the HUD, 0.77 sec to the instrument cluster, and 0.82 sec to the center console. The median glance durations were 0.86 sec on the expressway, 0.81 sec on the rural road, 0.68 sec on the suburban street, 0.79 sec on the urban street, and 0.87 sec while stopped at urban intersections. Younger drivers' median glance duration were 0.08 sec longer than older drivers. Also, the mean percentage of driving time spent looking at the targets was 3.7 percent higher for younger drivers than for older drivers.

The drivers' glance behavior to the visual targets showed that drivers were able to look at the visual targets for at least 0.3 sec in most cases. Therefore, when information needs to be obtained in one glance, it should be designed to be understood within this duration. In addition, the mean percentages of time that drivers were able to look at the targets can be used for estimating the duration of in-vehicle information presentations based on road type.

17. Key Words	18. Distribution Statement
drivers' visual behavior, displays, HUD, glance duration, IVHS, human factors, eye fixation, motor vehicles	Unrestricted.

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1. Introduction

In recent years, many types of intelligent vehicle systems have become available in the automotive market. These systems are designed to reduce drivers' workload. Since drivers' main task is to control the vehicle, this additional information from intelligent systems may distract them, instead of helping them. For example, more information may not be better, if drivers have to spend a long time to obtain and understand it. As a result, some intelligent vehicle systems might unintentionally increase drivers' workload, even though they are designed to reduce it.

Some cars have in-vehicle displays to present information from the intelligent vehicle systems. In-vehicle displays for these systems are installed in three main places within the drivers' field of view: in the instrument cluster, on the center console, or as a head-up display (HUD). Several indicators and meters are already installed in the limited space in the instrument clusters. To overcome the space limitations, some automotive companies have developed instrumentation with shared controls and displays. Those systems have an in-vehicle display in the instrument cluster, and present the most appropriate information according to the drivers' needs or the traffic condition. This alternative use of the instrument-cluster area might be a popular solution to reduce drivers' workload. Another common location for in-vehicle displays is on the center console. Many electric navigation systems, both after-market and factory-equipped systems, have installed liquid crystal displays (LCD) or cathode-ray tube (CRT) displays on the center console, because that location has enough space to house them. Another possible display location is the HUD area. This location is considered to be one that can reduce drivers' eye movements off the road, because of its proximity to the center of the drivers' visual field. For instance, some cars project the vehicle speed on the bottom of the front windshield to increase safety by reducing drivers' eye movements to the speedometer.

In-vehicle displays in these three locations usually present drivers complicated visual information. Nevertheless, that visual information is added to the conventional visual information for driving. The duration that drivers can keep looking at displays is limited, because when drivers look at in-vehicle displays, they can not obtain information from the road. The displayed information should not take longer to read than drivers can afford, in order to continue driving safely.

One approach to optimize in-vehicle display systems is to identify the duration and the frequency of drivers' glance behavior to the displays. Kishi, Sugiura, and Kimura (1992) investigated the average duration that drivers looked at the instrument cluster while driving on urban streets and highways in Japan. Their results showed that half of the drivers looked at the display for more than 2 seconds (sec), and 95 percent of the drivers looked at it for more than 1 sec. Drivers' visual behavior was also recorded with driving simulators. Popp and Farber (1991) determined drivers' visual behavior related to displays on the instrument cluster (approximately 15 degrees below the average drivers' eye-fixation point on the road) and the center console (30 degrees below). Drivers needed to look at the center-console location more often, and for a longer duration, to accomplish the same tasks.

Drivers' glance behavior may be different when focusing on each of the three display locations, because each has a different visual angle from the drivers' eye fixation point on the road. Okabayashi, Sakata, and Hatada (1992) determined that the drivers' eye-fixation point on the road was mainly located around the infinity point on the horizon, and it varied ±2 to 3 degrees vertically because of traffic conditions. Drivers' glances toward the displays begins from the eye-fixation point on the road, to the display, and ends by looking back to the road again. Therefore, drivers' visual behavior to in-vehicle displays should be identified as a cycle, originating from the drivers' eye fixation point on the road. Okabayashi, Furukawa, Sakata, and Hatada (1991) found that the drivers perceived visual tasks less accurately when the distance to the visual task increased, when the visual tasks were given on CRTs located between ±15 degrees horizontally and ± 5 degrees vertically. In their test, participants were instructed to look at the two different locations at the same time using both central and peripheral views. Their correct answer rate was worse when they used their peripheral view. In addition, Miura (1992) suggested that drivers mostly use a limited field of view to obtain the information for driving on the public road, and the usable field of view varies with the attentional demands of driving. Therefore, drivers' visual behavior to the in-vehicle displays may vary with their location in the drivers' view.

When information is displayed in the HUD location, drivers can detect the information without moving their eye fixation from the road. In addition, drivers' workload to recognize information would be reduced if they could perceive the information in their peripheral view, even if partially, before they actually look at it. For example Okabayashi, et al. (1991) stated that drivers perceived the visual tasks on HUDs more accurately because drivers were able to perceive the information partially before looking at it. However, intelligent vehicle systems show more complicated information than just vehicle speeds. When complicated information is displayed on in-vehicle displays, drivers have to read it with their central field of view. Therefore, the research concerning drivers' visual behavior to the displays for intelligent vehicle systems should determine their glance behavior to the display, rather than the drivers' information processing ability in their peripheral view. The duration that drivers can keep looking directly at the displays and the frequency of their glances to the displays, seem to be important factors to measure drivers' visual behavior.

Traffic conditions seem to affect drivers' visual behavior. Drivers move their eye fixation from the road to the display according to the importance of the information obtained by looking at the road and the displays. Spijkers (1992) determined that drivers looked at the road for different percentages of time, based on road type. Kayser and Hess (1991) reported that the frequency and duration of drivers' glance behavior varied while they were driving on urban streets, two-lane rural roads, and urban freeways. In addition, Verwey (1993) stated that traffic conditions affected drivers' visual performance, because the workload of the visual and cognitive processes varied by traffic condition. The attentional demand to monitor the traffic might be different between daytime and nighttime, and also between the traffic conditions on different road types. Hulse, Dingus, Fischer, and Wierwille (1989) developed a method for quantifying the attentional demand of driving based on sight distance, curvature, lane restriction, and road width. In the current experiment, traffic condition on the public road was separated into four road types: driving on expressways, rural roads, suburban streets, urban streets (both while driving and stopped).

The drivers' motivation to obtain information might affect their glance behavior. The quantification of the drivers' motivation seems to be difficult because their motivation varies with many factors including age and gender differences, and their interaction. For example, when information is extremely important to drivers, they may look at it immediately and for a long time. But if drivers feel they can obtain the information anytime they want, they may look at it whenever they want. Drivers may behave differently in these two situations. The longest duration that drivers can continuously look at the display is an important limitation to consider when developing in-vehicle display systems.

2. Project Overview

2-1. Objectives of the project

The main objectives of this project were:

(1) to identify how much attention various road types require, and

(2) to determine how much time is available to look at various displays:
  a) in three display locations (HUD, instrument cluster, center console),
  b) while driving under two sets of instructions: when drivers feel they can safely do, or when drivers feel comfortable to do.

Two dependent variables to determine drivers' visual behavior were obtained from these objectives:

(1) the duration drivers can continuously look at the displays
(2) the frequency of glances to the displays

These factors were considered as independent variables for determining drivers' visual behavior:

(1) display location	(HUD, instrument cluster, center console)
(2) road type	(expressway, rural road, city street)
(3) age	(younger and older drivers)
(4) gender	(men and women)
(5) time of day	(daytime and nighttime)
(6) drivers' motive	(look at displays safely or comfortably)

A preliminary test was undertaken to examine the importance of these independent variables, to eliminate any if they did not have significant effects on the dependent variables.

2-2. Preliminary examination

This preliminary examination concerned the importance of the independent variables, and the details are described in Chapter 3. Four drivers, two younger and two older, participated in this experiment during both daytime and nighttime. While driving on the test route, they were instructed to look at the visual targets either "as long as, and as often as, you feel safe to do so" or "... comfortable to do so." On-road experiments were carried out on the test route located in north east in Ann Arbor, Michigan. The test route consisted of an expressway (M-14, between Ford Road and Sheldon Road), a rural road (Ford Road, between Ann Arbor and Canton), and a suburban street (Sheldon Road in Canton).

The results of this pilot test showed that the two independent variables did not have any significant effects on the drivers' visual behavior. There was no significant difference between drivers' visual behavior during daytime and nighttime. Also, the difference in the drivers' visual behavior was small, when they felt "safe" or "comfortable" to look at the display. Therefore the main experiment was carried out only during daytime, and drivers were instructed to look at the visual targets when they felt "safe" to do so.

2-3. Main experiment - expressway, rural road, and suburban street

A large-scale experiment was carried out in July of 1993. The objectives of this experiment were to determine drivers' visual behavior as assessed by the following dependent variables:

(1) the glance duration (sec) to look at visual targets
(2) the frequency of glances (Hz) to look at visual targets
(3) the percentage of time that drivers look at the visual target (%), and
(4) vehicle operation data (vehicle speed, steering angle, and throttle opening ratio).

The independent variables were:

(1) display location	(HUD, instrument cluster, center console)
(2) road type	(expressway, rural road, suburban street)
(3) age	(younger and older drivers)
(4) gender	(men and women)

Twenty-two drivers, ten younger (age 26 to 35) and twelve older (age 60 and older), participated in this experiment. Participants were instructed to look at the visual targets (2 degrees of visual angle) "as long as, and as often as, you feel safe to do so." The visual targets were installed in three locations: HUD area, the center of the instrument cluster, and the top of the center console. Drivers' visual behavior was recorded by a NAC model EMR-V eye mark recorder, and vehicle operation was recorded by the data recording system in the test vehicle. The same test route as the preliminary examination was used in this experiment. The test route consisted of mostly straight and flat roads. Data collected while the test vehicle was stopped were not analyzed.

The results of this experiment showed that drivers' glance behavior to the targets was affected by display location and the road type. The effect of road type was more significant than the display location. Table 2-3-1 shows the summary data of drivers' glance behavior to each display location. Table 2-3-2 shows the effect of each independent variable and its interactions.

Table 2-3-1. Summary results of drivers' glance behavior to each display location.

Display location	Median glance duration (sec)	Mean frequency of glances (Hz)	Mean percentage of time glancing to display (%)
HUD	0.79	0.29	32
Instrument cluster	0.77	0.35	32
Center console	0.82	0.35	34

Table 2-3-2. The results of level-of-significance tests (F-test) concerning the effect of each independent variable and interactions on four dependent variables: glance duration, frequency of glances, percentage of time that drivers looked at the visual targets, and vehicle speed.

Independent variable	Dependent variable			
	Duration	Frequency	Percentage	Speed
Display location	++	+++	n/s	n/s
Road type	+++	++	+++	+++
Age	+++	+	n/s	n/s
Gender	n/s	+	+	n/s
Interaction				
Display location * Road type	+++	+++	+++	+++
Display location * Age	+++	++	n/s	n/s
Display location * Gender	++	+	n/s	n/s
Road type * Age	+++	+	+++	+++
Road type * Gender	+++	++	+++	+++
Age * Gender	+	+	n/s	n/s

(+++ : $\underline{p} \leq 0.001$, ++ : $\underline{p} \leq 0.01$, + : $\underline{p} \leq 0.1$, n/s : not significant)

Details of the main experiment are described in chapter 4.

2-4. Additional experiment - Urban street

As a result of the data analysis, it was confirmed that drivers' visual behavior is affected more by traffic conditions than by the visual target location. In the main experiment, Sheldon Road was used for the suburban-street condition, however, the definition of city streets might involve other road types, which are more complex and more congested. Therefore, an additional experiment was carried out in downtown Ann Arbor to determine drivers' visual behavior on urban streets.

In the main experiment, visual behavior was not analyzed while drivers were stopped at intersections because that experiment aimed to determine the drivers' visual behavior in three constantly moving traffic conditions. On the contrary, in this experiment, data while stopped at intersections were analyzed, because waiting at traffic signals was considered to be a common behavior in heavy traffic in a downtown area.

Another eight drivers participated in this additional experiment. The eye-mark recorder was not used because it restricted drivers' field of view and interfered severely in urban driving. Instead, a video camera on the left A-pillar recorded test participants' faces and eyes. The drivers' visual behavior was analyzed by investigating their eye movements relative to the visual targets. The drivers' eye movements toward the visual target in the HUD area were not detectable by this method. Therefore, only the drivers' visual behavior to two visual targets (instrument cluster and center console) were determined in this experiment. The results of this experiment were compared with the results of the main experiment.

Similar to the results of the main experiment, the results of the additional experiment showed that the effect of the driving state was more significant than the display location. Table 2-4-1 shows the effect of each independent variable and its interactions.

Table 2-4-1. The results of level-of-significance test (F-test) concerning the effect of each independent variable and interactions on dependent variables: glance duration, frequency of glances, and percentage of time that drivers looked at the visual targets.

Independent variable	Dependent variable		
	Duration	Frequency	Percentage
Driving state	+++	n/s	n/s
Display location	n/s	n/s	n/s
Gender	+++	n/s	+
Interaction			
Display location * Driving state	++	n/s	n/s
Display location * Gender	+++	n/s	n/s
Driving state * Gender	+++	n/s	n/s

(+++ : $p \leq 0.001$, ++ : $p \leq 0.01$, + : $p \leq 0.1$, n/s : not significant)

Details are described in chapters 6 and 7.

2-5. Conclusions

Driver's visual behavior to the three display locations on the five road types was investigated. The results of data analysis concerning the influence of the visual angle and the viewing distance to the target identified that the difference of the drivers' visual behavior to the three display locations was small. However, drivers looked at the target for the HUD over a greater range of durations than for the other two locations. Possible explanations are that the HUD has a different focal distance than its background, and that the background of the HUD target was dynamic as the car traveled.

The results of level of significance test showed the effect of the road type was more significant than the display location. In addition, the average values of these dependent variables did not vary significantly according the location of the targets. Therefore, when designing information to be presented on in-vehicle displays, the type of road that drivers are driving on can be used as a main factor to identify the drivers' ability to glance to the displays. The average values of each dependent variable on the five road types are shown in Table 2-5-1.

Table 2-5-1. The average values of dependent variables on each road type: the median glance duration, the mean frequency of glances, and the mean percentage of time that drivers looked at the targets.

Road type	Median glance duration (sec)	Mean frequency of glances (Hz)	Mean percentage of time (%)
Expressway	0.86	0.34	38
Rural road	0.81	0.35	35
Suburban street	0.68	0.30	25
Urban street (driving)	0.79	0.39	19
Urban street (stopped)	0.87	0.31	16

Table 2-5-2 shows some recommended durations to present information on in-vehicle displays. The fifth percentile value of each glance duration shows that drivers looked at the targets for at least that fifth percentile duration in most cases. Therefore, if information is designed to be understood by drivers within this duration, they can look at it in one glance. When information needs more than one glance to be understood, it should be presented for longer than the interval between glances obtained in this study, so drivers might be able to look at it again by the next glance. The interval of glances, the inverse of the frequency of glances, can be used to set the duration of information presentation. The mean percentage of time that drivers looked at the targets in Table 2-5-1 can be used to estimate the duration that drivers need to look at information while driving.

Table 2-5-2. Fifth percentile duration of all glances, and the mean and ninety-five percentile value of the interval of all glances to the in-vehicle displays on five types of roads.

Road type	Glance duration (sec)	Interval of glances (sec)	
	5 th percentile	Mean	95 th percentile
Expressway	0.33	2.94	5.68
Rural road	0.32	2.86	5.95
Suburban street	0.30	3.33	7.09
Urban street (driving)	0.27	2.56	12.20
Urban street (stopped)	0.27	3.23	5.43

Details are described in chapter 8.

3. Preliminary Examination

3-1. Objectives

The objective of this preliminary examination was to evaluate the importance of two independent variables:

(1) Time of day	(daytime and nighttime)
(2) Drivers' motive	(look at displays safely or comfortably)

The dependent variable to determine drivers' visual behavior was the duration that drivers would continuously look at the display.

3-2. Experiment

Four drivers, two younger (19-year-old woman, 23-year-old man) and two older drivers (60- and 64-year-old men), participated in this pilot test in May 1993. One driver from each age group was instructed to look at the visual target "as long as and as often as you feel safe to do so." The other driver in each group was instructed to look at the targets "as long as and as often as you feel comfortable to do so." The visual targets were 2-degrees-of-visual-angle dots, and they were installed in three locations: the HUD area, the center and the top of the center console. Drivers' visual behavior was recorded by a NAC model EMR-V eye-mark recorder. The test route consisted of an expressway (M-14, between Ford Road and Sheldon Road), a suburban street (Sheldon Road), and a rural road (Ford Road). It took 1.5 hours to complete, and each of the four drivers drove the test route both during the daytime and at night. Details of the equipment and the test route are provided in the next chapter.

In addition, a survey was carried out with 12 drivers to investigate their stereotypes for the words "safe" and "comfortable" when they were used to describe traffic conditions. Drivers were instructed to rate the level of stress of seven words: "safe," "comfortable," "easy," "danger," "uncomfortable," "unsafe," and "difficult." The scale ranged from 1 (not stressful) to 7 (stressful). The five words besides "safe" and "comfortable" were included to avoid emphasis on these two words.

3-3. Results

(1) Drivers' visual behavior at night and during the day

This pilot study showed that drivers' visual behavior was not significantly different between daytime and nighttime. Therefore the main experiment was carried out only during the daytime. The results of the data analysis are shown in Table 3-3-1. Because the histogram of the drivers' glance duration seemed to have a similar shape with a log normal standard distribution, the level of significance between the two conditions was analyzed after the data were transformed into logarithm base ten.

Table 3-3-1. Summary statistics of all glance duration data (by time condition).

	Day	Night
Number of glances	990	1040
Mean duration (sec)	1.11	1.01
Median duration (sec)	0.87	0.86
First quartile (sec)	0.54	0.62
Third quartile (sec)	1.32	1.25

The glance durations under the two time conditions were not significantly different ($F(1, 2030) = 0.208$, $p = 0.648$). Also the difference between the condition medians was very small (0.01 sec). The mean frequency to look at the visual targets was the same during the day and at night, 0.18 Hz.

(2) Visual behavior when drivers feel "safe" and "comfortable" to look at displays

The difference in drivers' visual behavior between two conditions was examined, when they feel "safe" to look at displays, and when they feel "comfortable" to do so. The results of data analysis are shown in Table 3-3-2.

Table 3-3-2. Summary statistics of all glance duration data (by drivers' motive).

	Safe	Comfortable
Number of glances	846	1184
Mean duration (sec)	1.04	1.07
Median duration (sec)	0.82	0.90
First quartile (sec)	0.52	0.62
Third quartile (sec)	1.31	1.28

The glance durations under the two conditions was significantly different from each other ($F(1, 2030) = 15.318$, $p < 0.001$), however the difference between their means (0.03 sec), and medians (0.08 sec) was small. Also, the differences of their variances and standard deviations were small.

This preliminary examination aimed to determine the difference of drivers' glance behavior relative to the targets under two sets of instructions when "they feel safe to look " and when "they feel comfortable to do." If their glance behavior is not different, the main experiment does not have to be conducted with both words even though the results of the preliminary examination showed differences between two words. The following section describes the results of a survey concerning drivers' perception of the words.

(3) Drivers' rating for "safe" and "comfortable"

The results of the rating showed a significant difference between the two word groups (Kolmogorov-Smirnov test, $p \leq 0.001$):
(1) "comfortable," "safe," "easy," and
(2) "danger," "uncomfortable," "unsafe," "difficult."
However, the words "safe" and "comfortable" were not rated significantly different from each other (Kolmogorov-Smirnov test, $p = 0.186$). The mean values of each word are shown in Figure 3-3-1.

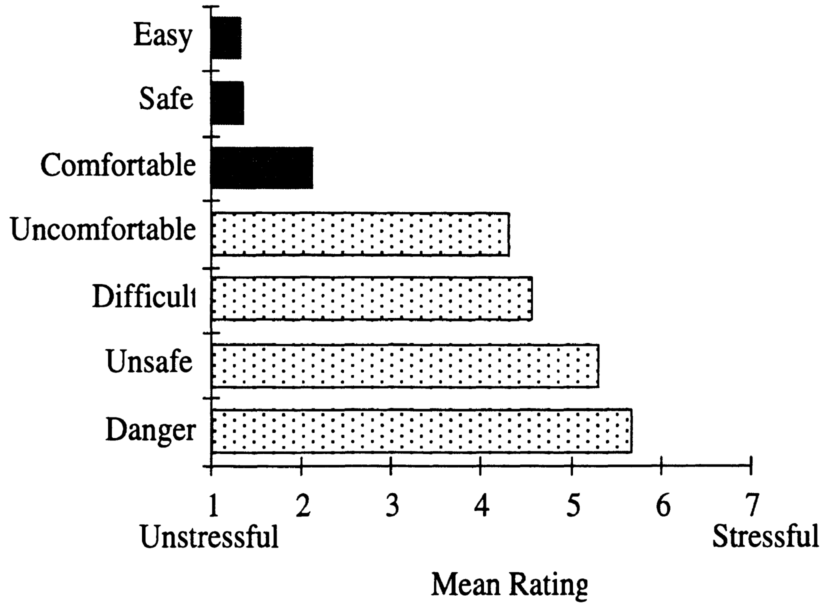


Figure 3-3-1. Drivers' rating of stressfulness associated with words used to describe traffic conditions.

Even though only a limited number of drivers participated in this survey, its results support those of the pilot test. Drivers did not behave differently when they were told to look at the targets when they felt it was safe and when they felt comfortable to do so. It seems that drivers might not be able to distinguish between "safe" and "comfortable," when they are used to describe traffic conditions. Therefore, the main experiment was carried out to determine the drivers' visual behavior only when they felt "safe" to look at the display.

3-4. Conclusions

The results of this preliminary examination showed that the effects of the two independent variables (time of day and two sets of instructions) were relatively small on the drivers' visual behavior. Therefore, the main experiment was carried out only during the daytime, and drivers were instructed to look at the visual targets only when they felt “safe” to do so.

4. Main Experiment - expressway, rural road, and suburban street

4-1. Equipment

(1) Test vehicle

A 1991 Honda Accord LX Wagon was used as the test vehicle. It has been equipped for human factors experiments, as described below. Drivers' visual behavior was recorded by a NAC model EMR-V eye-mark recorder, and vehicle operation was recorded by a data collection system in the test vehicle.

Drivers' visual behavior recording unit

The NAC model EMR-V is a popular eye-mark recorder for measuring drivers' visual behavior. It measures eye movements by the reflected image of an infrared LED. A narrow infrared light from the LED reflects from the cornea, and the subjects' eye fixation is detected by the location of the reflection. The eye-fixation point is superimposed on the scene from drivers' forward view. This image can be videotaped by a VHS video recorder. Also, the data analyzer of the NAC model EMR-V eye-mark recorder has both analog and digital data (30 Hz) outputs. Videotaped data were used to analyze drivers' visual behavior in this experiment. Drivers' visual behavior was obtained from the movements of their right eyes, because the left eye camera unit was detached from the eye camera's head set to avoid restricting the view on the left side. Drivers could see their left side through the small window (30 mm x 30 mm) for the left eye camera. Figure 4-1-1 shows a picture of the NAC model EMR-V eye-mark recorder with both right and left eye cameras attached.

Figure 4-1-1. NAC model EMR-V eye-mark recorder.

Vehicle operation recording system

The test vehicle was equipped to record: vehicle speed, steering angle, and throttle opening ratio. Vehicle speed data were obtained from the original speed-sensor in the transmission of the test vehicle. Its data sampling frequency was 10 Hz, and the accuracy is to ±0.5 mph when the vehicle speed is more than 10 mph, and ±1 mph when it is 10 mph or less. Steering angle data were determined by a potentiometer attached to the steering shaft. The data sampling frequency was 30 Hz, and the accuracy of the data is ±1 degree. The throttle opening ratio data were obtained from the original throttle position sensor in the throttle body sampled at 30 Hz.

During data collection, these data were stored in the 80 megabyte hard disk of a Gateway 2000 33-MHz 486 computer installed in the rear section of the test vehicle. An AT MIO-16 board was used to import data from the sensors to the 486 computer. After the experiment, the stored data were copied to a Bernoulli 90 megabyte disk.

Data recording system configuration

The system configuration of data recording units is shown in Figure 4-1-2.

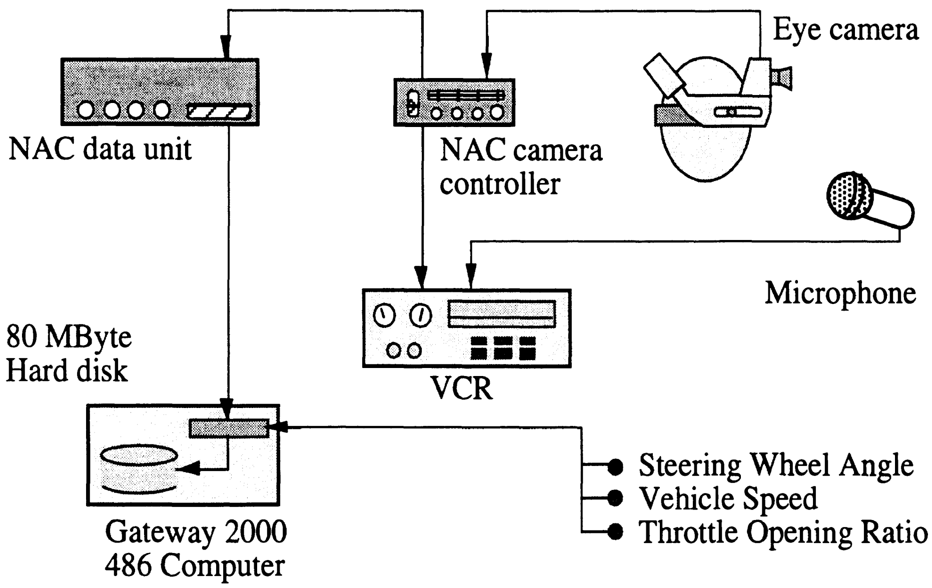


Figure 4-1-2. System configuration of the test vehicle.

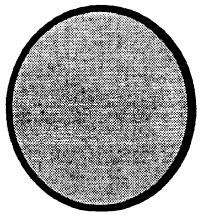
Most control units were installed in a steel frame rack that replaced the left rear passenger seat. They were operated by the experimenter sitting in the other rear seat. A 10-inch LCD monitor displayed the current vehicle data for the experimenter. A 5-inch TV monitor displayed the drivers' forward view and their eye-fixation points as shown by the eye-mark recorder. The control unit of the eye mark recorder was also installed in the middle of the rack. Its viewfinder and remote control unit were extended to the front passenger seat, because the experimenter used them from the front passenger seat to calibrate the eye-mark recorder.

The 486 computer, eye-camera data-output unit, and DC/AC converter were installed in the rear cargo area.

(2) Size of visual targets

The visual targets, small circles made from paper, had a constant amount of visual information. The size of each visual target was 2-degrees-of-visual-angle to keep drivers' glances at one location. In addition, when drivers are looking at a 2-degrees-of-visual-angle target, they can not see the road scene in their central fields of view (the fovea) where drivers recognize shapes and colors. Thus, a 2-degrees-of-visual-angle circle was considered as the most appropriate size of visual target for this experiment.

Figure 4-1-3 shows a sample visual target, drawn to scale. When the distance between the drivers' eyes and a target is between 700 mm and 730 mm, the visual angle of this target is approximately 2 degrees. Three visual targets were cut from a sheet of paper, and taped on the target locations with a transparent sheet. Color pencils were used to shade the visual targets.



Visual angle: 2 degree
Diameter : 25 mm
Outline : 0.8 mm, black
Colors : blue, green, and red

Figure 4-1-3. Example of the visual target.

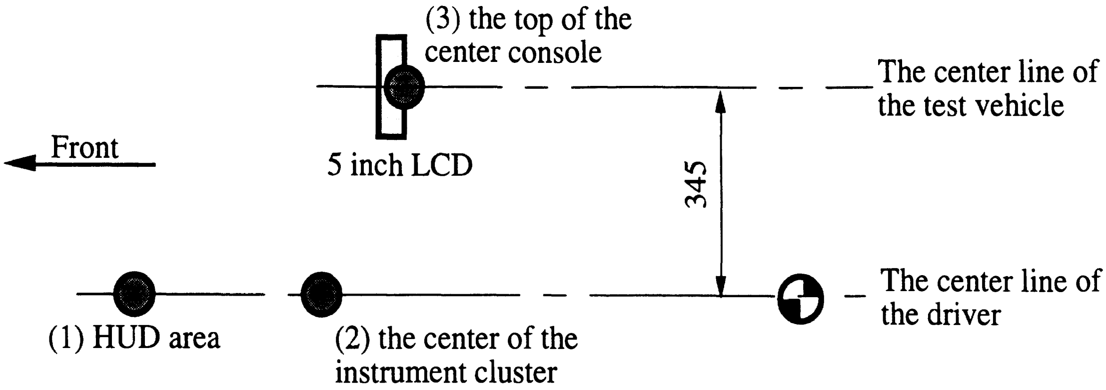
(3) Location of visual targets

One circle was installed in each of the three locations in the test vehicle:

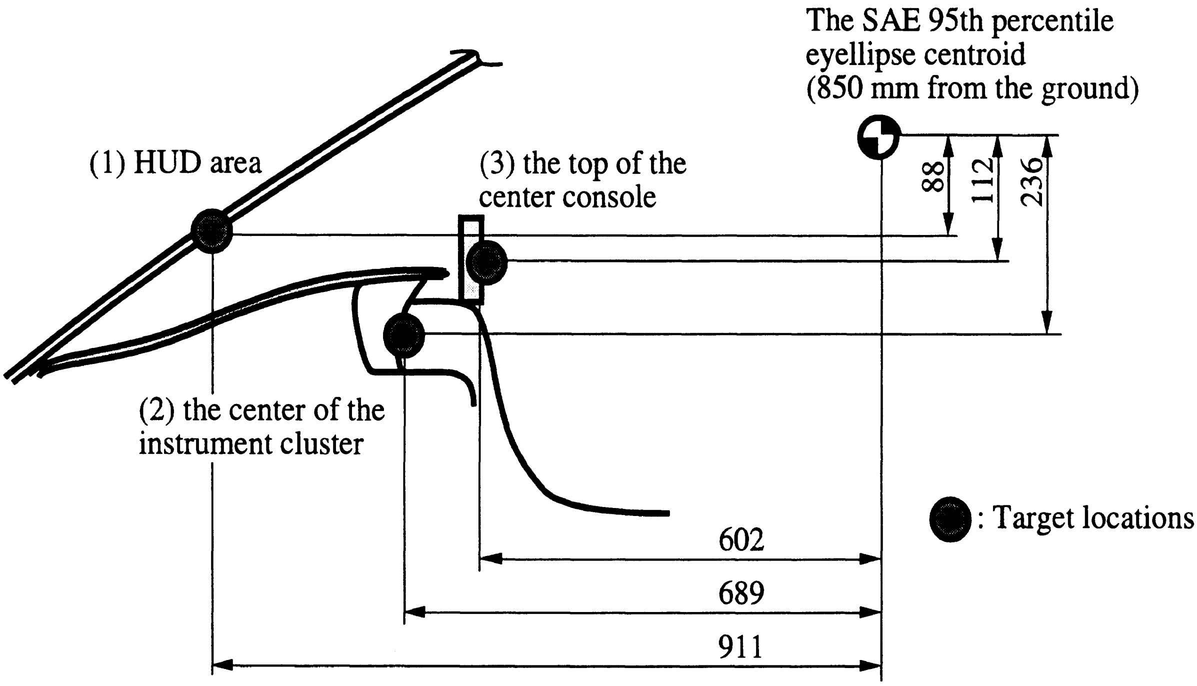
(1) HUD area (on the front windshield, slightly below center of drivers' frontal view),
(2) the center of the instrument cluster (on the center of the speedometer), and
(3) the top of the center console

Figure 4-1-4 shows the distances between the targets and the SAE J941 95th-percentile eyellipse centroid. A 5-inch LCD was installed on the top of the center console in the test vehicle. The visual target for the center-console condition was located at the center of the display, because that location was considered to be one of the most appropriate locations to put displays for intelligent vehicle systems.

HUD images are often projected to the center of drivers' frontal view, while some HUD systems show the image to the side. Considering the purpose of the HUD, it should be located closer to the drivers' glance points toward the road. However, the HUD image should not distract drivers from watching traffic. Therefore, the most appropriate location of the visual target for the HUD area was reasoned to be slightly below center of drivers' normal glance points.



Plan View



Left-side View (all dimensions are in mm)

Figure 4-1-4. The visual target locations.

Table 4-1-4. Location of the visual targets.

	Color	Viewing distance to the target (mm)			Visual angle to the target (degree)		
Plan view		Min.	Ctr.	Max.	Min.	Ctr.	Max.
(3) Center console	Green	610	694	781	26.2	29.8	34.4
Left-side view							
(1) HUD area	Blue	818	917	1016	4.1	6.7	9.4
(2) Instrument cluster	Red	639	735	832	16.8	20.3	24.3
(3) Center console	Green	517	616	715	8.3	12.3	16.6

Viewing distances and visual angles to the target locations from the SAE J941 95th-percentile eyelipse (minimum, center, and maximum values).

The distances in Table 4-1-4 were defined as the linear distances between the center of the SAE 95th-percentile eyellipse centroid and the center of the visual targets. Also, the visual angles were defined as the angles between these two eye fixations: when drivers look directly forward at the same height with the SAE 95th-percentile eyellipse centroid, and when they look at each visual target.

4-2. Test conditions

The drivers' visual behavior was recorded only after they were asked to look at the visual targets when they felt "safe" to do so. This experiment was carried out during daylight hours between 8:30 and 19:30. To avoid heavy traffic, no subjects were run between 16:00 and 18:00. During testing, visibility was always good, and road surfaces were dry.

Data were obtained while drivers were driving on three different types of roads: expressways, rural roads, and suburban streets. Figure 4-2-1 shows the test route map.

M-14 (between Ford Road and Sheldon Road) was chosen as the expressway traffic condition. There are a few curves in this section, but they are very gentle. Thus, it was assumed that drivers would behave very similarly when they drove on a completely straight and flat road. Ford Road is a straight rural road, and it was used to determine the drivers' visual behavior in a rural-traffic condition. Sheldon Road was used for the suburban-streets condition. It is one of the main roads in that area, and there are many stores, offices, and houses along its two- and four-lane segments. Road characteristics are shown in Table 4-2-1.

Table 4-2-1. Road characteristics of the test route.

Road type	Road name	Number of lanes	Traffic flow (*1) (vehicles /day)	Speed limit mph (km/h)	Distance mile (km)
Expressway	M-14	4	67500	65 (104)	10.1 (16.2)
Rural road	Ford Road	2	9200	55 (88)	9.1 (14.6)
Suburban street	Sheldon Road	2 and 4	12300 ~ 21600	35 (56) & 40 (64)	4.4 (7.0)

(*1) see reference (10).
(*2) mph: mile per hour, km/h: kilometer per hour

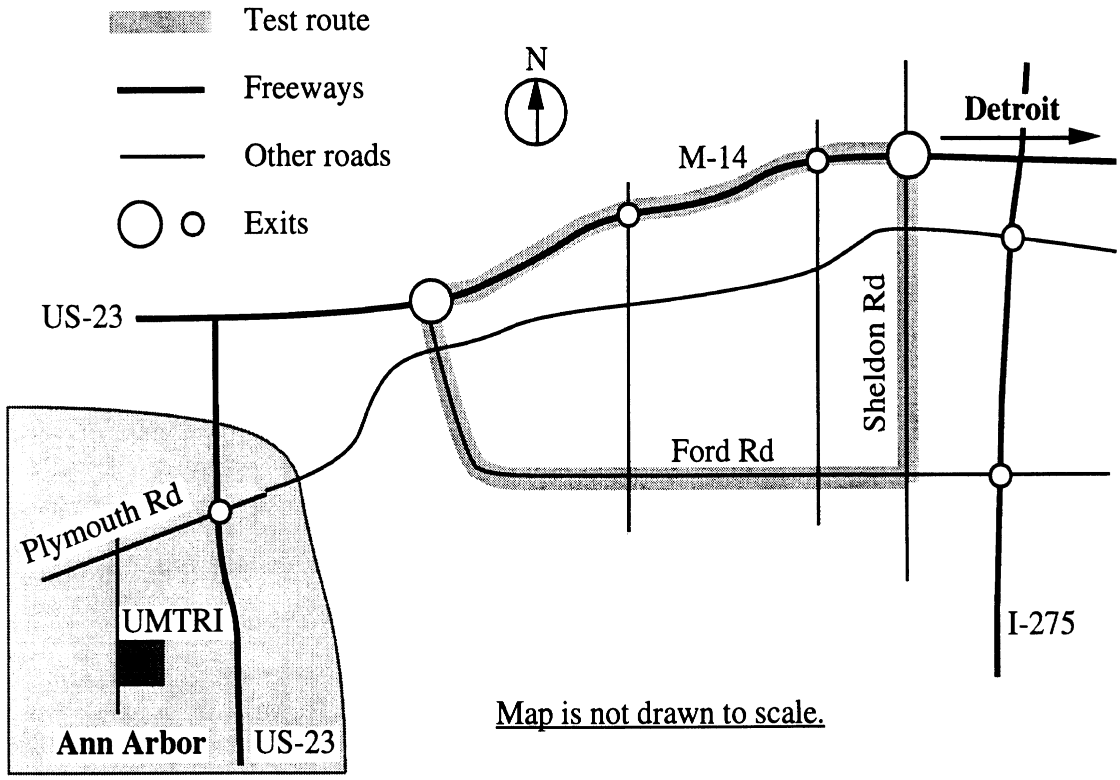


Figure 4-2-1. Test route map (north-east of Ann Arbor, Michigan).

4-3. Test participants

(1) Age and gender

Twenty-two drivers participated in this experiment, and they received twenty-five dollars for a one-and-a-half-hour session. None of them were commercial drivers, and most of them (14 of 22) indicated they were familiar with the roads in the test route. The drivers consisted of two age groups: younger (age 26 to 35) and older drivers (age 60 and older). The younger drivers' mean age was 30, and the older drivers' mean age was 67. Equal numbers of men and women participated. Table 4-3-1 shows the number of drivers in each group, and their ages.

Table 4-3-1. Drivers' age in each group.

Age group	Gender	Count (person)	Mean age (years)	Age range (min. - max.)
Younger	Men	5	31	29 - 33
	Women	5	30	26 - 35
Older	Men	6	67	61 - 74
	Women	6	67	60 - 75

(2) Vision

The NAC model EMR-V eye-mark recorder, used to determine drivers' visual behavior, can determine eye movements even if drivers wear soft contact lenses or eye glasses. However, drivers who wore hard contact lenses were not able to participate in this study. In addition, many old drivers wore bifocal or trifocal glasses, and those glasses reduced the accuracy of the visual-behavior-data. The ranges of the drivers' visual acuity was between 20/30 and 20/13 (Landolt rings) in younger drivers, and 20/50 and 20/17 in older drivers. All drivers who participated in this experiment were considered to have acceptable levels of visual acuity for driving on public roads.

4-4. Test procedure

This experiment was carried out in July, 1993. After test participants arrived at UMTRI, they were told the purpose of the experiment and the test conditions. The test conditions were described in the official consent form (Appendix 1). Their biographical data (age, gender, occupation, most frequently driven cars, annual mileage, and familiarity with the test route) were recorded on the form shown in Appendix 2. Drivers' visual acuity was examined by a Titmus vision tester before the test drive, and they were asked about their need for vision correction. Also, they were requested to present their valid driver licenses.

After drivers adjusted the steering tilt, seat position, and mirrors to a comfortable positions, the experimenter explained the visual targets and the drivers' tasks. The experimenter referred to the three targets by their color. The experimenter, who sat in the rear seat, told drivers: "You can see three circles in front of you. They are visual targets. During the experiment, you will be asked to look at them one at a time, as often as, and as long as, you feel safe to do so." The order to look at the targets was randomized.

Drivers were instructed to go to the intersection of Plymouth Road and Ford Road by taking either US-23 or Plymouth Road. There were two ways to approach that intersection, because the data collection was carried out on the test route in both directions randomly: (1) Ford Road, to Sheldon Road, and M-14, and (2) M-14, to Sheldon Road, and Ford Road. Plymouth Road was used when the data collection started from Ford Road, and US-23 was used when it was started from M-14. After drivers arrived at the intersection, they were instructed to park the test vehicle in the broad shoulder near the intersection. All data collection instruments were set up, and the eye-mark recorder was put on drivers and calibrated according to its standard procedure. Drivers' visual behavior and vehicle operation were recorded while driving on the test route, and drivers were reminded to look at one of the visual targets "as long as, and as often as, you feel safe to do so." During data collection, drivers were told the current location at major intersections, and the distance to the next road or major intersection. The experimenters' instructions were recorded on a VCR to identify when a new visual target was specified to drivers. Because of the view restriction caused by the eye camera, the experimenter also monitored the traffic around the drivers.

After the data collection was completed, drivers were instructed to park at the same intersection as before, for removal of the eye camera and equipment shutdown. Only Plymouth Road was used to return to UMTRI to avoid using the complex interchange of M-14 and US-23. At the UMTRI building, drivers signed the official payment form and were paid for their participation.

The detailed experimental procedure is in Appendix 3.

5. Results of the Main Experiment

5-1. Summary of the data analysis

(1) Definitions of the variables

During the experiment, the drivers looked at one of the visual targets as long as, and as often as, they felt safe to do so. Therefore, the drivers looked at the visual targets periodically, and watched the traffic between glances to the visual targets. Figure 5-1-1 shows an example of a driver's visual behavior data in a trial. The trial began at the time T_a, and ended at T_b. Thus, the total duration of the trial was (T_b - T_a). In the example, the driver looked at the visual target three times (the shaded areas) during the trial. The duration of each glance was ΔT_n, ΔT_{n+1}, and ΔT_{n+2} (sec).

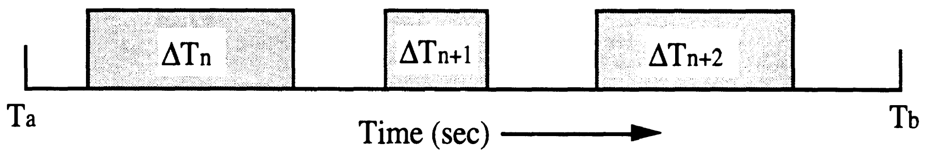


Figure 5-1-1. Example of drivers' visual behavior.

The total glance duration to look at the visual target was obtained by summing the duration of each glance. The mean frequency of glances (Hz) was calculated from the number of glances in the trial and the trial duration.

The frequency of glances to look at visual targets (Hz)

$$= (T_b - T_a) / N$$

where $T_b - T_a$ = total duration of the trial
N = number of glances in the trial

The percentage of time that drivers looked at an individual visual target was the ratio of the duration that a driver could look at the visual target to the duration of the trial.

The percentage of time that drivers look at the visual target (percent)

$$= \Sigma\ (\Delta T_n + \Delta T_{n+1} + \Delta T_{n+2} + \ldots\ldots..) / (T_b - T_a)$$

where $T_b - T_a$ = total duration of the trial
ΔT_n = duration of glance (n)

(2) Data analysis method

Drivers' eye movements were videotaped during the test sessions. The analysis of the drivers' visual behavior was based on the videotaped image. Therefore, these data may contain at least ±0.033 sec error, because the eye movements were recorded at a 30 Hz sampling frequency. Each duration of the glance to a visual target and the number of glances were obtained as raw data from the videotaped image. While the analyst was watching the videotaped image, which was replayed at the normal playback speed, the analyst pushed the "1" key at the beginning of each glance to the visual target, and the analyst pushed the "2" key at the end of the glance. A Hypercard program was prepared to measure the duration and number of glances. It returned the duration between the two key-presses and counted the number of the key-presses. In all test conditions, histograms of each data set were analyzed to decide the method of the statistical analysis. Subsequently, summary statistics of each test condition were obtained by a statistical analysis program, SYSTAT 5. The level of significance among the test conditions was examined by two programs: Super ANOVA for the F-test, and SYSTAT 5 for the t-test.

For carrying out the analysis of variance, the glance-duration data were normalized by transforming the data into logarithm base ten. Figure 5-1-2 shows the histogram of the raw glance-duration data and Figure 5-1-3 shows the histogram of the transformed data. The histogram of the transformed data seemed to have a normal standard distribution (kurtosis = 0.52, and skewness = 0.67). The summary statistics of the glance-duration data are shown in Table 5-1-1.

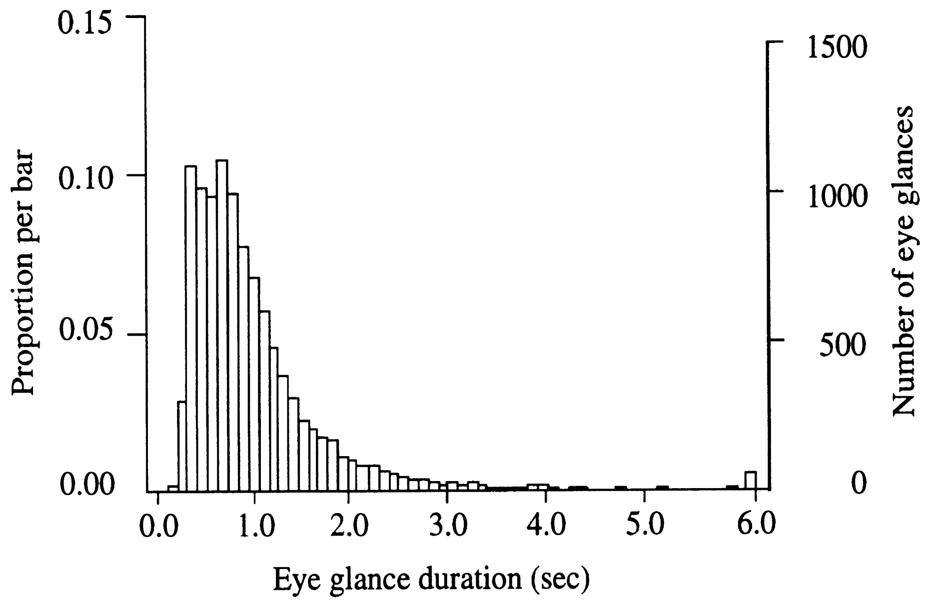


Figure 5-1-2. Histogram of the all glance-duration data.

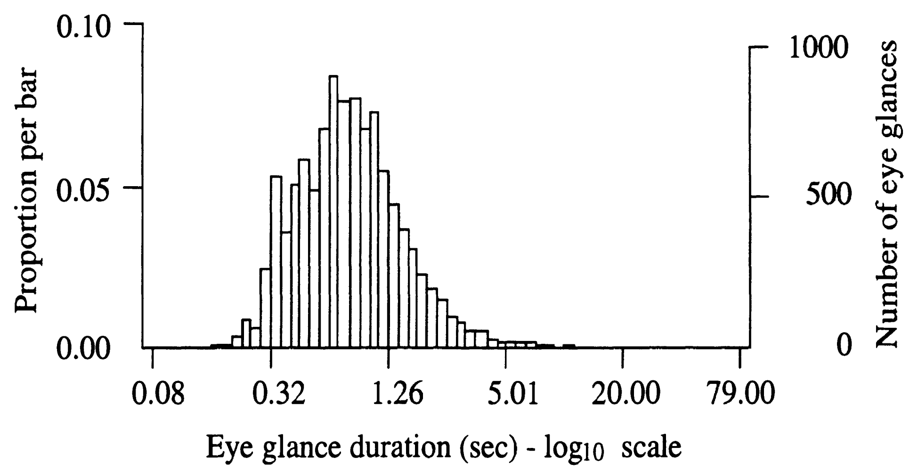


Figure 5-1-3. Histogram of the all glance-duration data (transformed into $\log_{10}$).

Table 5-1-1. Summary statistics of all glance-duration data (n = 10660 glances).

	Glance duration
Mean duration (sec)	0.99
Median duration (sec)	0.80
First quartile (sec)	0.53
Third quartile (sec)	1.17

A result of the F-test on all glance-duration data showed a significant interaction among the test conditions (display locations x road types x age groups x genders = 3 x 3 x 2 x 2, $F(8, 10660) = 6.128$, $p \leq 0.001$). The details of their effects are described in the following sections.

One hundred ninety eight means were obtained from this experiment (subjects x display locations x road types = 22 x 3 x 3) for the frequency of the glances, the percentage of time that drivers looked at the visual targets, and the vehicle-operation data. The histogram of the frequency-of-glances data seemed to have a standard normal distribution (skewness = 0.03, and kurtosis = -0.02). The F-test was used to examine the level of significance. The F-test was also used to examine the level of significance for the percentage of time that drivers looked at the visual target (skewness = 0.68, kurtosis = 0.39) and vehicle operation data.

5-2. Glance duration to look at the visual targets

(1) Display locations

The display locations affected the glance duration to look at visual targets in some cases. Drivers looked at the center-console location longer than the other two locations, and the instrument-cluster location had the shortest median glance duration. The median glance duration for each display location was similar (0.77 ~ 0.82 sec). For these two locations, their first and second quartile value of glance duration showed that they had similar dispersions of the glance-duration data. On the other hand, the first and second quartile value of glance-duration for the HUD location had wider dispersion than those two locations, even though the median glance duration was between the instrument-cluster and center-console locations. The summary statistics are shown in Table 5-2-1, and results of the level-of-significance tests are shown in Table 5-2-2. Drivers' glance duration for the instrument-cluster and the HUD locations were significantly different, but the other two combinations were not significantly different.

Table 5-2-1. Summary statistics of the glance duration for the three different display locations.

	Display location		
	HUD	Instrument cluster	Center console
Number of glances	3136	3733	3791
Mean duration (sec)	1.10	0.92	0.97
Median duration (sec)	0.79	0.77	0.82
First quartile (sec)	0.43	0.52	0.58
Third quartile (sec)	1.20	1.12	1.13

Table 5-2-2. Results of level-of-significance test (F-test and Scheffe's S test).

dependent variable = glance duration				
Independent variable	Degrees of freedom	Sample size	F	p
Display locations	2	10660	5.397	0.005
HUD vs. Instrument cluster	1	6869	s	0.006
HUD vs. Center console	1	6927	s	0.632
Instrument cluster vs. Center console	1	7524	s	0.109

(s : Scheffe's S test)

The visual angle and viewing distance to the targets were weakly correlated with the median glance duration to each target. The median glance duration increased when visual angles to the targets increased, and it decreased when viewing distance to the targets increased. Figure 5-2-1 shows the relationship between median glance duration and visual angle, and the median glance duration and viewing distance.

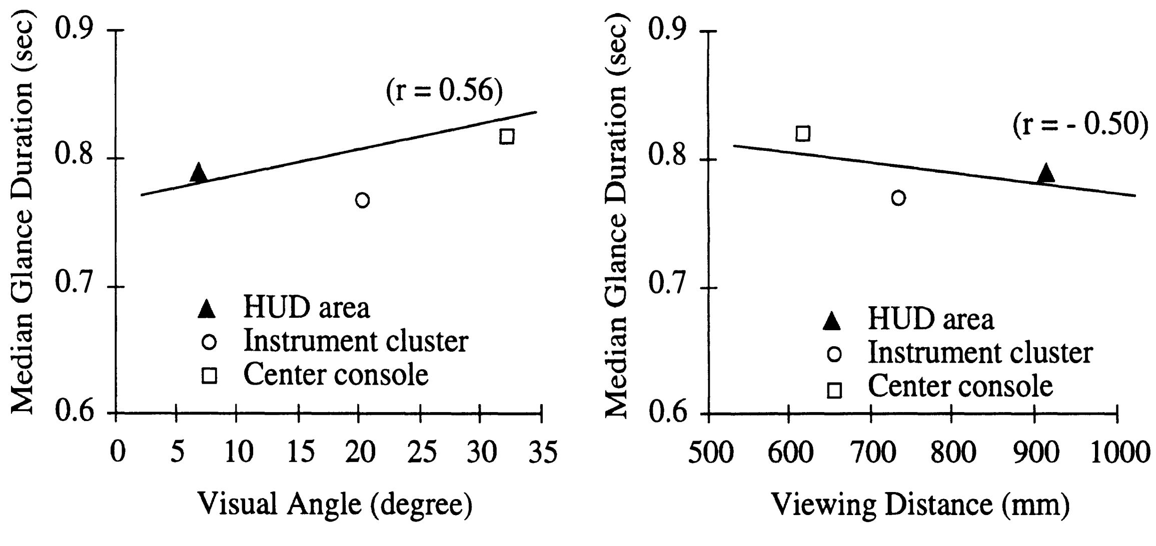


Figure 5-2-1. Relationship between the median glance duration and visual angle (left), and the median glance duration and viewing distance (right) to look at the three different display locations.

(2) Road types

Road types also affected the glance duration for the display locations. On the expressway, the median duration was 0.18 sec longer than on the suburban street. The first and third quartile values of glance duration show that the dispersions of drivers' glance duration were similar when driving on the expressway and rural roads. However, the dispersion of glance duration on suburban streets was smaller than the other two road types. The summary statistics are shown in Table 5-2-3. Table 5-2-4 shows the results of level-of-significance tests, and it showed the drivers' glance duration on the three road types were significantly different each other.

Table 5-2-3. Summary statistics of the glance duration for displays while driving on the three different road types.

	Road type		
	Expressway	Rural road	Suburban street
Number of glances	3953	3954	2753
Mean duration (sec)	1.09	1.00	0.84
Median duration (sec)	0.86	0.81	0.68
First quartile (sec)	0.57	0.53	0.43
Third quartile (sec)	1.23	1.20	0.97

Table 5-2-4. Results of level-of-significance test (F-test and Scheffe's S test).

dependent variable = glance duration				
Independent variable	Degrees of freedom	Sample size	F	p
Road types	2	10660	107.516	≤ 0.001
Expressway vs. Rural roads	1	7907	s	≤ 0.001
Expressway vs. Suburban streets	1	6706	s	≤ 0.001
Rural roads vs. Suburban streets	1	6707	s	≤ 0.001

(s : Scheffe's S test)

(3) Interaction between display locations and road types

An interaction was observed in a 3 x 3 analysis of variance between display locations and road types ($F(7, 10660) = 29.109$, $p \leq 0.001$). Figure 5-2-2 shows their interactions. Even though drivers were driving on three different road types, they looked at the visual target on the center console longer than the other two locations. On the other hand, the median glance duration to the visual target on the instrument cluster was the shortest in the three traffic conditions. However, the effect of display location was smaller than the traffic condition.

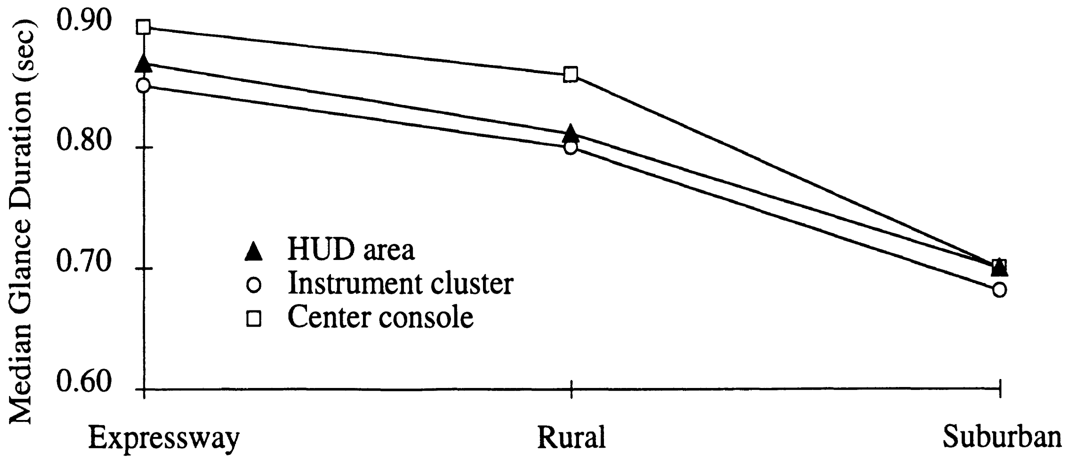


Figure 5-2-2. Interaction between display locations and road types.

(4) Age and gender

Younger drivers (between ages 25 and 35) looked at display locations for longer durations than older drivers (age over 60), however the difference in the medians of the two age groups was only 0.08 sec. Table 5-2-5 shows the summary statistics of the glance duration for display locations, by age and gender. The results of level-of-significance tests are shown in Table 5-2-6. The difference due to gender was also small (0.02 sec in their medians), and it was not significant. A 2 x 2 analysis of the level of significance showed a weak interaction between age and gender.

Table 5-2-5. Summary statistics of the glance duration by age and gender.

	Age		Gender	
	Younger	Older	Men	Women
Number of glances	4750	5910	4830	5830
Mean duration (sec)	1.02	0.96	0.99	0.99
Median duration (sec)	0.84	0.76	0.80	0.78
First quartile (sec)	0.55	0.52	0.53	0.50
Third quartile (sec)	1.25	1.13	1.17	1.08

Table 5-2-6. Results of level-of-significance test.

dependent variable = glance duration				
Independent variable	Degree of freedom	Sample size	F	p
Age	1	10660	37.625	≤ 0.001
Gender	1	10660	0.524	0.469
Age * Gender	2	10660	5.397	0.045

(5) Interactions between display locations and age, and display locations and gender

The interaction between age and display locations was significant in a 2 x 3 analysis ($F(3, 10660) = 12.351$, $p \leq 0.001$). Younger drivers looked at the three display locations longer than the older drivers, especially for the HUD location. The interaction between the gender and display locations was also significant (F(3, 10660) = 3.701, $p = 0.002$). However, the differences for each display location were small (0.01 ~ 0.05 sec in medians). Figure 5-2-3 shows their interaction.

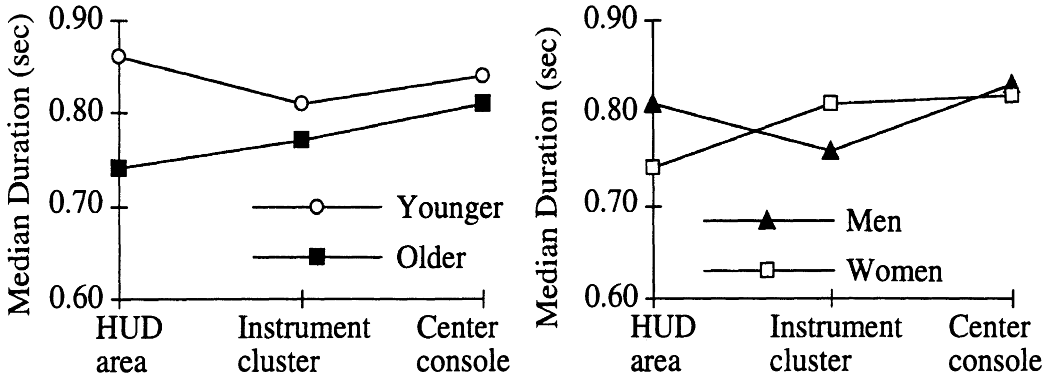


Figure 5-2-3. Interaction between display locations and age (left), and interaction between display locations and gender (right).

(6) Interactions between road types and age, and road types and gender

A result of a 3 x 2 analysis showed the significant interaction between road types and age (F(3, 10660) = 63.008, $p \leq 0.001$). The median duration to look at visual targets was the same on expressways and suburban streets. However younger drivers looked at visual targets than older drivers when they were driving on rural roads. A significant interaction was observed between road types and gender (F(3, 10660) = 3.701, $p \leq 0.002$). Male drivers looked at visual targets slightly longer than female drivers, and the difference due to gender was small in expressway and rural traffic conditions. In suburban traffic conditions, the median glance duration of female drivers was longer than that of male drivers, and the difference was relatively greater than in the other two traffic conditions. Figure 5-2-4 shows the interaction on the glance duration between road types and age, and road types and gender.

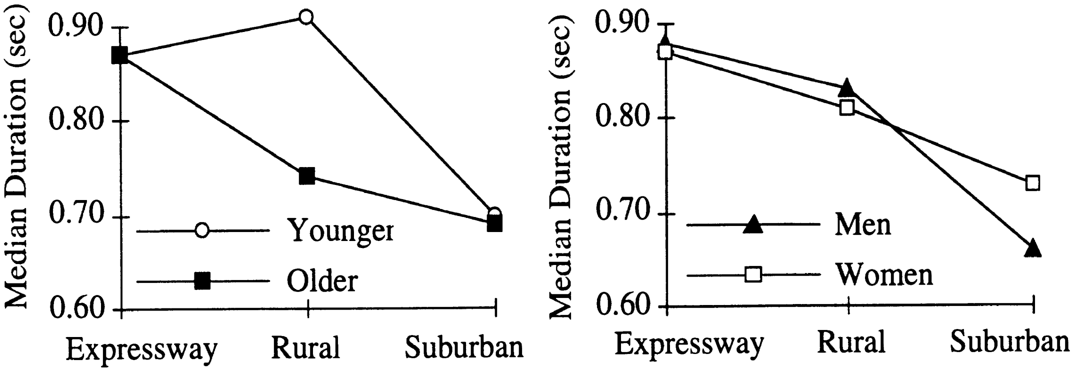


Figure 5-2-4. Interaction between road types and age (left), and interaction between road types and gender (right).

5-3. Frequency of glances to the visual targets

(1) Display locations

Frequencies were the same in the means for the instrument-cluster and the center-console locations, as were their standard deviations. However, drivers looked at the HUD location less often than the other two locations. Table 5-3-1 shows the summary statistics of the frequency of glances to the three display locations. Table 5-3-2 shows the results of level-of-significance tests for display locations. The HUD location had significant differences in drivers' frequency of glances from the other two locations, however no significant differences were observed between the instrument-cluster and the center-console locations.

Table 5-3-1. Summary statistics of the frequency of glances for the three different display locations.

	Display location		
	HUD area	Instrument cluster	Center console
Mean frequency (Hz)	0.29	0.35	0.35
Standard deviation (Hz)	0.09	0.11	0.11

Table 5-3-2. Results of level-of-significance test (F-test and Scheffe's S test).

dependent variable = frequency of glances

Independent variable	Degrees of freedom	Sample size	F	p
Display location	2	198	7.748	≤ 0.001
HUD vs. Instrument cluster	1	132	s	0.004
HUD vs. Center console	1	132	s	0.003
Instrument cluster vs. Center console	1	132	s	0.995

(s : Scheffe's S test)

(2) Road types

There were no differences in the means and the standard deviations between expressways and rural roads . However, for suburban streets, drivers looked at display locations less often than the two road types. Table 5-3-3 shows the summary statistics of the data. Drivers' visual behavior on suburban streets was significantly different from what it was on expressways and rural roads. The difference between the expressways and rural roads conditions was not significant. The results of level-of-significance tests are shown in Table 5-3-4.

Table 5-3-3. Summary statistics of the frequency of glances to look at displays while driving on the three different road types.

	Road type		
	Expressway	Rural road	Suburban street
Mean frequency (Hz)	0.34	0.35	0.30
Standard deviation (Hz)	0.11	0.10	0.10

Table 5-3-4. Results of level-of-significance test (F-test and Scheffe's S test).

dependent variable = frequency of glances				
Independent variable	Degree of freedom	Sample size	F	p
Road type	2	198	4.735	0.010
Expressway vs. Rural roads	1	132	s	0.944
Expressway vs. Suburban streets	1	132	s	0.049
Rural roads vs. Suburban streets	1	132	s	0.020

(s : Scheffe's S test)

(3) Interaction between display locations and road types

On the three types of roads, the mean frequencies of glances at visual targets on the instrument cluster and in the center console are almost the same. In contrast, drivers looked at the HUD area location less often than the others. The interaction between display locations and road types was significant ($F(7, 198) = 3.378$, $p = 0.001$). On suburban streets, drivers looked at visual targets less often than when they were on rural roads. Figure 5-3-1 shows the interaction between display locations and road types.

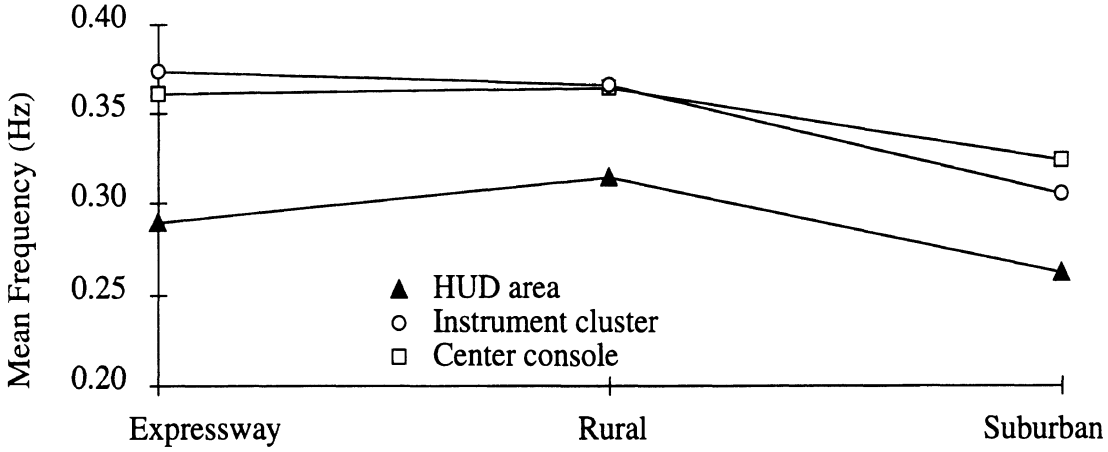


Figure 5-3-1. Interaction between display locations and road types.

(4) Age and gender

Younger drivers looked at display locations significantly more often than older drivers did ($F(1, 198) = 4.099$, $p = 0.044$), and women looked more often than men ($F(1, 198) = 3.477$, $p = 0.064$). Both age groups and both genders were significantly different. However their differences were small in means and standard deviations. Those two factors had a significant interaction ($F(2, 198) = 3.058$, $p = 0.030$). Table 5-3-5 shows the summary statistics of frequency of glances. Figure 5-3-2 shows the interaction between age and gender.

Table 5-3-5. Summary statistical of the frequency of glances by age and gender.

	Age		Gender	
	Younger	Older	Men	Women
Number of data	90	108	99	99
Mean frequency (Hz)	0.35	0.32	0.32	0.34
Standard deviation (Hz)	0.10	0.11	0.09	0.12

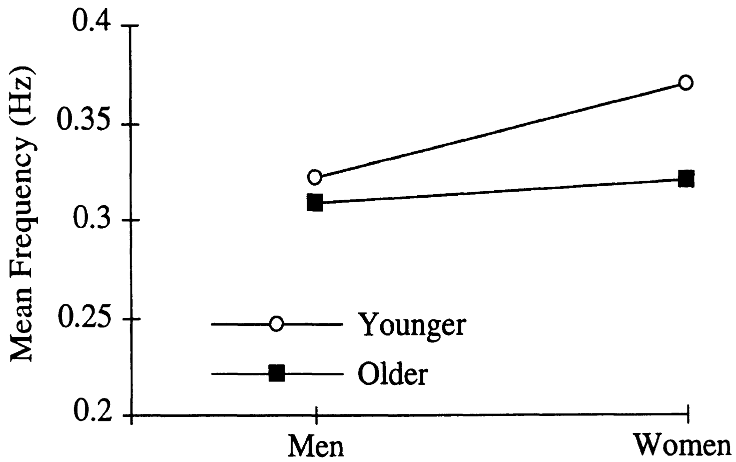


Figure 5-3-2. Interaction between age and gender.

(5) Interactions between display locations and age, and display locations and gender

The interaction between display locations and age was significant ($F(1, 198) = 4.080$, $p = 0.002$). In all of the three display locations, the mean glance frequencies of younger drivers were larger than the older drivers. Even if drivers looked at the two different display locations (on the center-console location and in the instrument cluster), the difference of their mean frequencies was not large. But for the HUD location, the difference of the mean frequency of glances between two age groups was more significant than the other locations. Female drivers' mean frequencies were significantly higher than male drivers, and the interaction between display locations and gender was significant ($F(1, 198) = 2.881$, $p = 0.016$). Figure 5-3-3 shows the interaction on the frequency of glances between display locations and age, and display locations and gender.

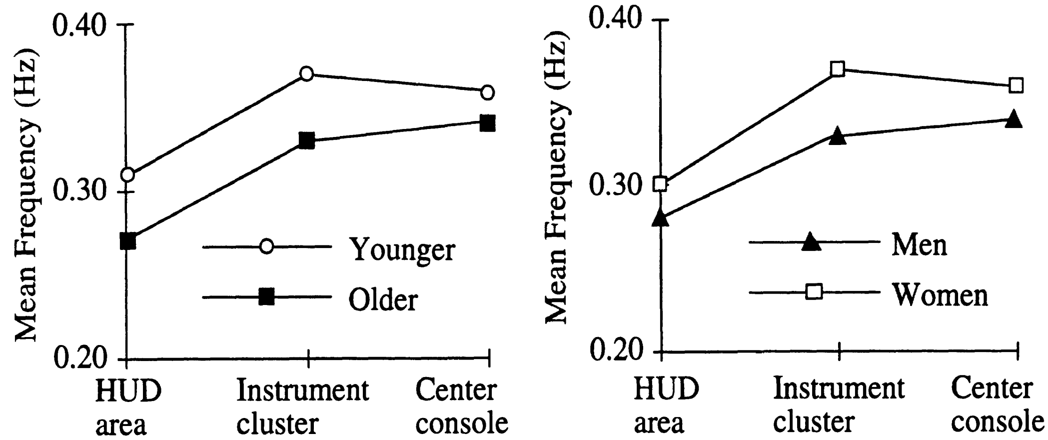


Figure 5-3-3. Interaction between display locations and age (left), and interaction between display locations and gender (right).

(6) Interactions between road types and age, and road types and gender

A result of a 3 x 2 analysis showed an interaction between road types and age ($F(1, 198) = 2.792$, $p = 0.019$). The mean frequencies of younger drivers were larger than the older drivers' on the three road types. The suburban condition had the lowest frequencies in both younger and older drivers. As with the interaction between road types and age, the interaction between road types and gender was also significant ($F(1, 198) = 3.903$, $p = 0.002$). In addition, the suburban-streets condition had the lowest frequencies of all conditions. However the differences from the others were smaller than the differences between two age groups. Figure 5-3-4 shows the interactions between road types and age, and road types and gender.

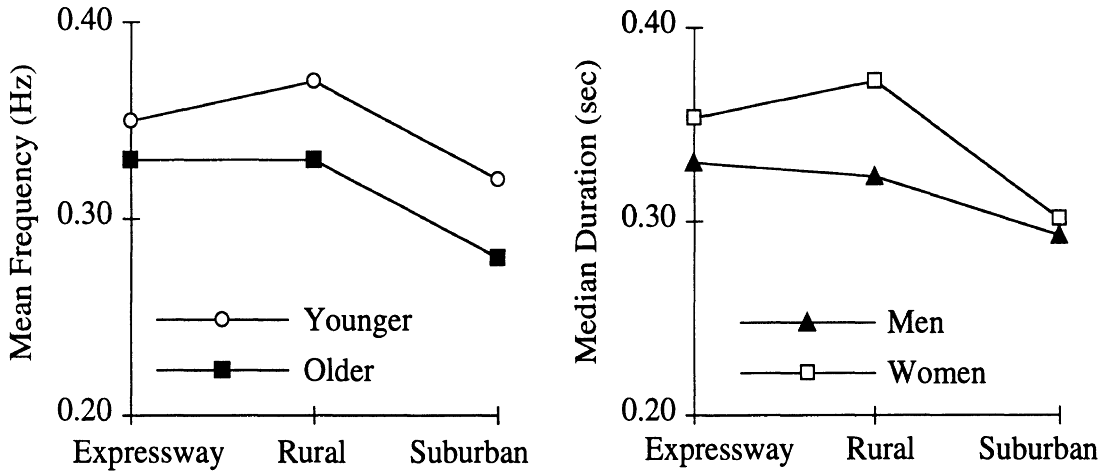


Figure 5-3-4. Interaction between road types and age (left), and interaction between road types and gender (right).

5-4. Percentage of time that drivers look at the visual targets

(1) Display locations

No significant effects of the display locations were observed among this data analysis ($F(2, 198) = 0.398$, $p = 0.677$). The mean percentages of time that drivers looked at visual targets were 32 percent for the HUD and the instrument-cluster locations, and 34 percent for the center-console location, their standard deviations were 15.6 percent and 17.0 percent. The analysis was based on 198 means (22 drivers x 3 display locations x 3 road types).

(2) Road types

The percentage of time that drivers looked at visual targets was significantly different among the three road types. While the drivers were driving on the suburban street, they looked at the visual targets only 25 percent of the time; this was 10 percent shorter than while they were driving on the rural road, and 13 percent shorter than while on the expressway. The differences between the suburban-street condition and the other two conditions were more significant than the difference between the expressway condition and the rural-road condition. The standard deviations increased along their mean values. The suburban-street condition had the least standard deviation (13.2 percent), compared with the rural-road condition (14.5 percent), and the expressway condition (17.6 percent). Table 5-4-1 shows the results of level-of-significance tests.

Table 5-4-1. Results of level-of-significance test (F-test and Scheffe's S test).

dependent variable = percentage of time				
Independent variable	Degree of freedom	Sample size	F	p
Road types	2	198	13.043	≤ 0.001
Expressway vs. Rural roads	1	132	s	0.528
Expressway vs. Suburban streets	1	132	s	≤ 0.001
Rural roads vs. Suburban streets	1	132	s	0.001

(s : Scheffe's S test)

(3) Interaction between display locations and road types

The interaction between display locations and road types was significant in a 3 x 3 analysis ($F(7, 198) = 3.364$, $p = 0.001$). When drivers looked at the visual targets on the HUD area and the instrument cluster, the mean percentages of time to look at them on expressways were longer than on the other two types of roads. However, the decreasing of the mean percentages was smaller when drivers looked at the center console. On suburban streets, drivers looked at visual targets the smallest percentage of time. Figure 5-4-1 shows the interaction between display location and road types.

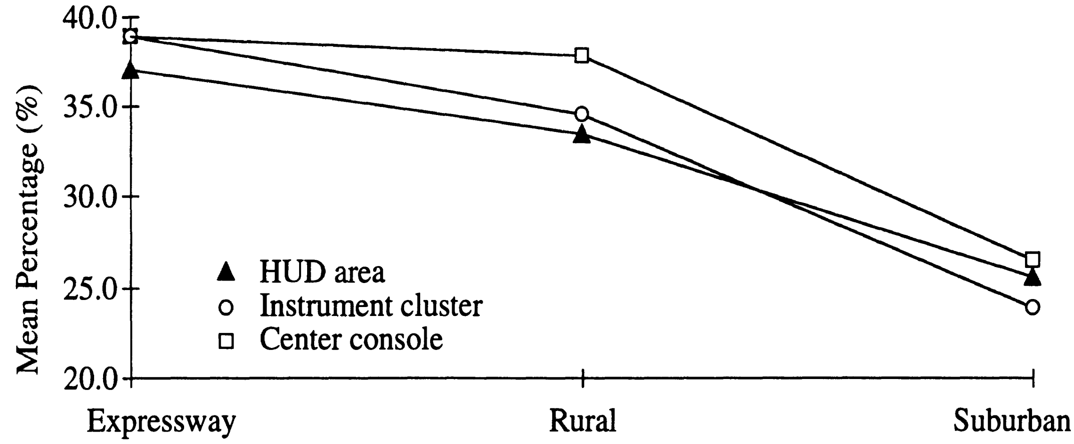


Figure 5-4-1. Interaction between display locations and road types.

(4) Age and gender

The younger drivers looked at the visual targets more (+3.7 percent) than did the older drivers, and the female drivers looked at the visual targets more (+4.6 percent) than did the male drivers. The difference between the two age groups was not significant ($F(1, 198) = 2.651$, $p = 0.105$). However the difference between the two genders was significant ($F(1, 198) = 4.108$, $p = 0.046$). The standard deviations of these data were large (between 14.4 and 17.3 percent). Figure 5-4-2 shows the significant interaction between age and gender ($F(2, 198) = 2.358$, $p = 0.073$). Table 5-4-2 shows the summary statistics of the percentage of time that drivers looked at display locations.

Table 5-4-2. Summary statistics of the frequency of glances by age and gender.

	Age		Gender	
	Younger	Older	Men	Women
Number of data	90	108	99	99
Mean percentage (%)	34.9	31.2	30.6	35.2
Standard deviation (%)	14.4	17.3	14.6	17.3

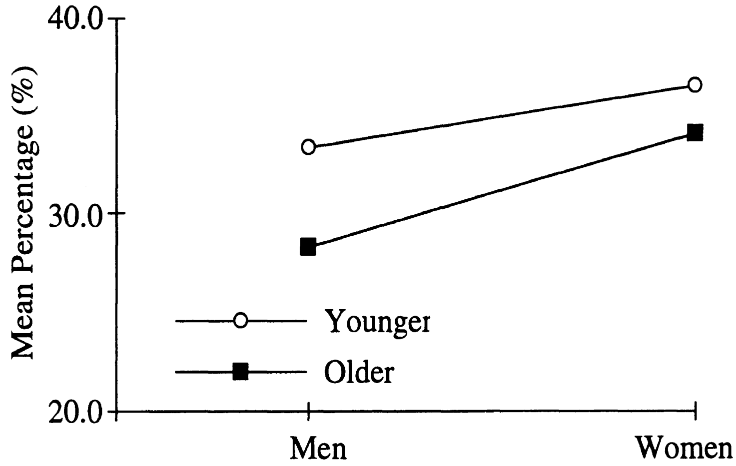


Figure 5-4-2. Interaction between age and gender.

(5) Interaction between display locations and age, and display locations and gender

No interactions were observed between the display locations and age ($F(3, 198) = 0.724$, $p = 0.606$), and between the display locations and the gender ($F(3, 198) = 1.052$, $p = 0.389$).

(6) Interaction between road types and age, and road types and gender

The interaction between the road types and age was significant in a 3 x 2 analysis ($F(3, 198) = 6.465$, $p \leq 0.001$). Both younger and older drivers looked at visual targets almost the same percentage of time while they were driving on expressways and suburban streets. However, on rural roads, younger drivers looked at visual targets a slightly greater percentage (+1.2 percent) than while they were driving on expressways, even though older drivers looked a smaller percentage of time (-6.5 percent). The interaction between road types and gender was also significant ($F(3, 198) = 6.202$, $p \leq 0.001$). Female drivers looked a greater percentage of time (+3.2 ~ +5.4 percent) than male drivers while driving on three different types of road. Figure 5-4-3 shows interactions between road types and age, and between road types and gender.

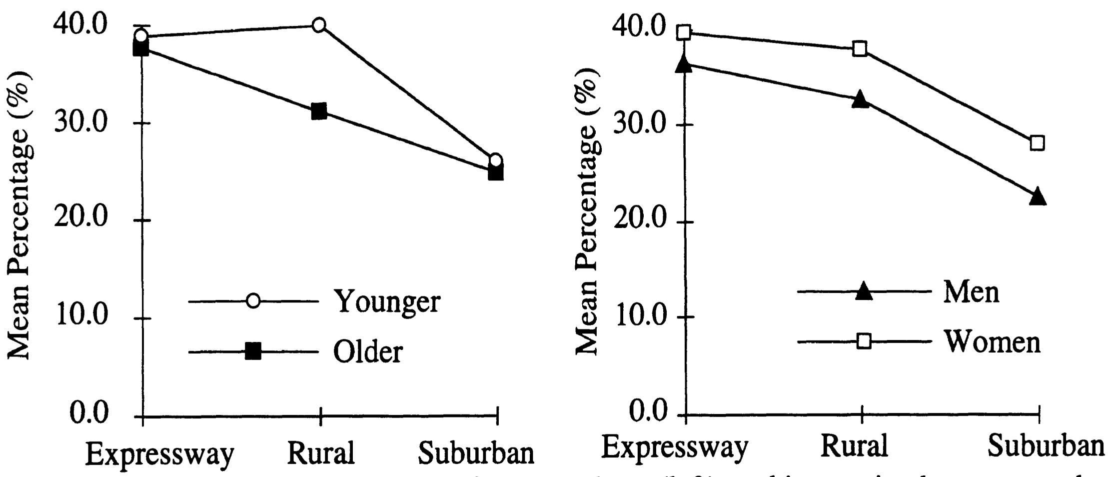


Figure 5-4-3. Interaction between road types and age (left), and interaction between road types and gender (right).

5-5. Vehicle Speed

The mean vehicle speeds corresponded to the speed limit on each road. The mean speed on the suburban street was the slowest, and the expressway was the fastest. The standard deviation of the vehicle speed on expressway was only 1.2 mph (1.92 km/h) and it was smaller than the other two road types. Table 5-5-1 shows the mean and the standard deviation of the vehicle speed during the experiment. The differences among the three traffic road types were significant ($F(2, 198) = 525.912$, $p \leq 0.001$).

Table 5-5-1. Summary statistics data of the vehicle speed data on each road type.

	Road type		
	Expressway	Rural road	Suburban street
Mean vehicle speed : mph (km/h)	62.0 (99.2)	51.8 (82.9)	30.0 (48.0)
Standard deviation : mph (km/h)	1.2 (1.92)	5.7 (8.32)	4.4 (7.04)

Details of the data analysis concerning the drivers' vehicle operations are described in Appendices 6 to 8.

6. Additional Experiment - urban street

6-1. Objectives

This experiment was carried out to determine the drivers' visual behavior on urban streets. The main objectives of this additional experiment were:

(1) to obtain drivers' visual behavior data on urban streets, and compare it with the data from suburban streets

(2) to determine drivers' visual behavior while stopped at urban intersections

The dependent variables to determine drivers' visual behavior were:

(1) the duration that drivers can continuously look at the display,
(2) the frequency of glances to the display,
(3) the percentage of time that drivers look at the display,
(4) the drivers' vehicle operation data

The independent variables for determining drivers' visual behavior were:

(1) Display location	(instrument cluster and center console)
(2) Driving state	(while driving and while stopped at intersections)
(3) Gender	(men and women)

6-2. Test conditions

The drivers' visual behavior was collected only after they were asked to look at the visual targets when they felt "safe" to do so. This experiment was carried out only during the daytime between 9:30 and 16:00, except during lunch time (between 12:00 and 13:30) to avoid pedestrians. During the experiment, visibility was always clear and road surfaces were dry.

Drivers' visual behavior was obtained while they were driving on urban streets in the central business district in downtown Ann Arbor: William, State, Liberty, and Main Streets. Figure 6-2-1 shows the test route map.

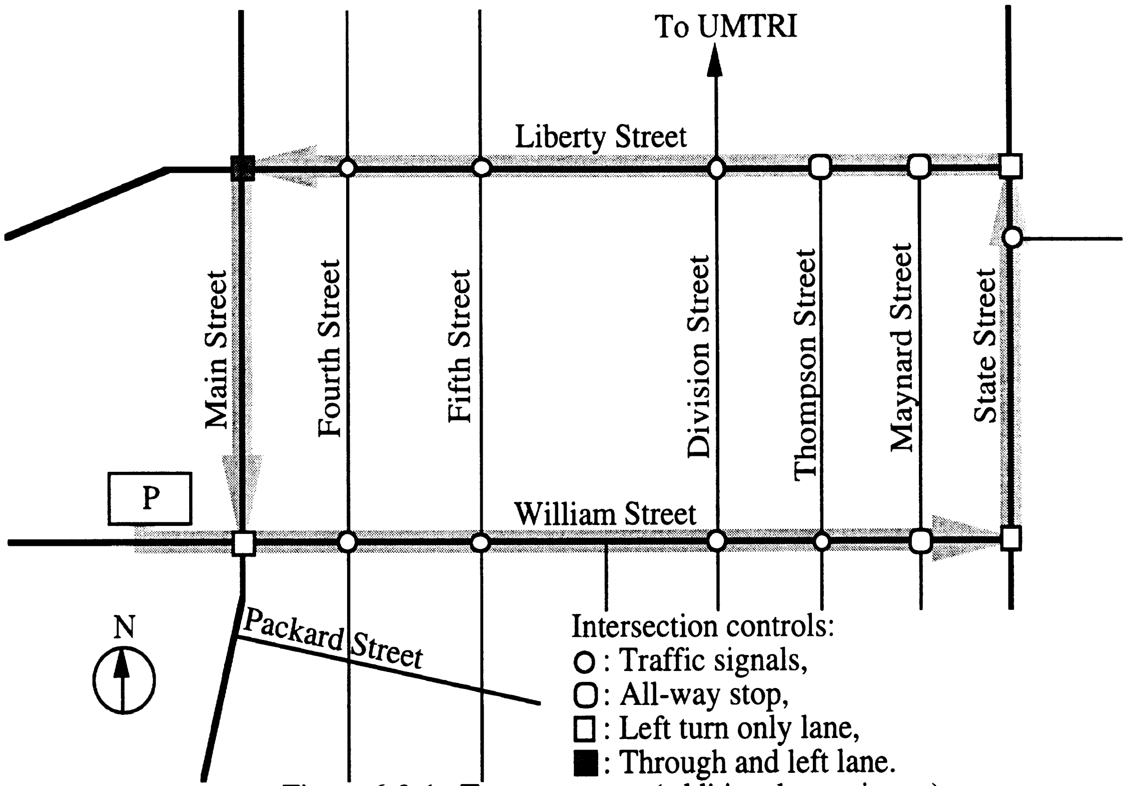


Figure 6-2-1. Test route map (additional experiment).

The test route for this experiment consisted of four straight streets that made one rectangular loop route. There were three left turns from the left-turn-only lanes, and another one from the through and left-turn lane without a left-turn arrow signal. Drivers drove through several intersections, but they had to merge into the "drive through lane" at some intersections. Many cars were parked on either one or both sides of the streets, but occasionally some delivery trucks blocked streets. Also, pedestrians and cyclists, while usually on the sidewalk, sometimes crossed the test route suddenly. Similar to the Sheldon Road suburban area, there were many buildings along the route. In Ann Arbor, however, they are much closer to the road and they often blocked drivers' view. The road characteristics are shown in Table 6-2-1.

Table 6-2-1. Road characteristics of the test route.

Street name	Number of lanes	Traffic flow (*1) (vehicles/day)	Speed limit mph (km/h)	Distance mile (km)
William	2 and 4	7200	25 (40)	0.4 (0.6)
State	2	10000	25 (40)	0.1 (0.2)
Liberty	2	9700	25 (40)	0.4 (0.6)
Main	2	16400	25 (40)	0.1 (0.2)

(*1) see reference (10)
(*2) mph: mile per hour, km/h: kilometer per hour

A public parking lot near the intersection of William and Main Streets was used to set up instruments.

6-3. Equipment

(1) Test vehicle

The same test vehicle used in this experiment was used in the main experiment (a 1991 Honda Accord LX Wagon). Drivers' vehicle operations were recorded by the data-collection system in the test vehicle: vehicle speed, steering angle, and throttle-opening ratio. However, the NAC model EMR-V eye mark recorder was not used to record drivers' visual behavior, because drivers could not see their peripheral field of view, due to the eye mark recorder's view restriction. Instead, a Panasonic video camera with a WV-LM15T zoom lens on the left A-pillar recorded drivers' eye movements. Details of the test vehicle are described in Chapter 4-1 "test vehicle."

(2) Visual targets

The same two-degrees-of-visual-angle visual targets that were used in the previous experiments were used in this experiment. Their locations were HUD area, the top of the center console, and the center of the instrument cluster. Because the eye movements to the visual target in the HUD area were not distinguishable from the glance to the forward road scene, this experiment investigated two visual target locations: the top of the center console, and the center of the instrument cluster. The visual target in the HUD area was not used for data collection, but it was installed there to keep the test condition the same as the main experiment, and to make the data comparable. Details of their size and locations are described in chapter 4-1 "size of visual targets" and "locations of visual targets."

6-4. Test participants

Four male and four female drivers participated in this experiment. They received fifteen dollars for a one-and-a-half-hour session. None of them were commercial drivers, and many of them (six of eight drivers) answered they were familiar with the roads in the test route. Because this experiment was considered to have high risk for traffic accidents, data were collected only from younger drivers. They were between ages 23 and 30, with mean an age of 27.

Drivers' visual acuity was between 20/33 and 20/13 (Landolt ring), and they had acceptable visual acuity for driving on public roads. They were allowed to use their visual aids for driving, however drivers who needed to wear eye glasses did not participate in this study.

6-5. Test procedure

This experiment was carried out between November 4 and 8, 1993. At the beginning of the experiment (in the UMTRI building), test participants were told the purpose of the experiment and the test conditions. Drivers confirmed the test conditions by signing the official consent form (Appendix-4). The same biographical form (Appendix-2) was used to obtain their biographical data. The experimenter checked drivers' visual acuity by a Titmus vision tester before the test drive. Also, drivers were requested to present their valid driver licenses.

The same visual task was given to the drivers. They were instructed to go to the intersection of William and Main Streets by taking Plymouth Road. After arriving at the intersection, they were instructed to park the test vehicle in a public parking lot near the intersection. All data-collection instruments were set up in the parking lot. The angle, iris, and focus of the video camera on the left A-pillar were adjusted to obtain the highest resolution of the drivers' eyes. After the instrument was set up, drivers were allowed to drive the test route twice to become familiar with the traffic patterns. At the end of the practice laps, drivers were asked if they were comfortable with continuing this drive with the visual task. When they agreed, the experimenter told them to begin the data collections. Only one visual target was given per lap of the test drive with counterbalancing the order. Drivers drove the test route three times looking at each of the three visual targets once. The experimenters' instructions were recorded in a VCR to identify when a new target was specified to drivers. At the end of the third lap, they were told to park in the same parking lot.

Drivers used Division Street and Plymouth Road to return to the UMTRI building. There, drivers signed the official payment form and were paid for their participation.

The detailed experimental procedure is in Appendix 5.

7. Results of the Additional Experiment

7-1. Summary of the data analysis

The data analysis for the additional experiment was carried out using the same procedure as the main experiment. The glance-duration data was transformed into logarithm base ten, and the F-test was used to examine the level of significance. However, the level of significance was not examined between the road types in the main experiment and this additional experiment. The road types in the main experiment were straight and had constant traffic flow. As a result of constant traffic flow, drivers did not have to maneuver the test vehicle often nor rapidly. In contrast, traffic conditions on urban streets varied, and drivers were required to merge, turn, and stop along the test route. If the traffic condition on urban streets had allowed drivers to drive at a constant speed, and to pass through all intersections, the data could have been compared with the data of the main experiment. In addition, data were obtained from a small number of drivers (eight drivers). Also, only younger drivers were used (between ages 23 and 30 years old). Therefore, the level of significance of the data from the main experiment and the additional experiment was not examined.

Because urban traffic often required drivers to stop at intersections, drivers' visual-behavior data were separated into two groups by vehicle speed: while drivers were driving on the test route and while they were stopped at intersections. Drivers' vehicle-operation data were analyzed, including the data collected while they stopped at intersections.

7-2. Glance duration to look at the visual targets

(1) Driving states

While drivers were stopped at intersections, their median glance duration was 0.14 sec longer than while they were driving on urban streets. The difference between the two driving states was significant ($F(1, 1638) = 13.672$, $p \leq 0.001$). The summary statistics of the glance duration on urban streets are shown in Table 7-2-1.

Table 7-2-1. Summary statistics of the glance-duration data by driving state.

	Driving state	
	Driving	Stopped
Number of glances	972	666
Mean duration (sec)	1.23	1.63
Median duration (sec)	0.79	0.87
First quartile (sec)	0.47	0.50
Third quartile (sec)	1.34	1.70

(2) Display locations

The differences between the two display locations were not significant, ($F(1, 1638) = 0.028$, $p = 0.867$), neither while drivers were driving on urban streets nor while they were stopped at intersections. However, the glance duration for each display location was significantly different between two driving states ($F(1, 1638) = 13.672$, $p \leq 0.001$). The dispersions of the data were similar for both conditions. Table 7-2-2 shows the summary statistics of the glance duration. The interaction between display locations and driving states was significant in a 2 x 2 analysis ($F(2, 1638) = 4.719$, $p = 0.003$).

Table 7-2-2. Summary statistics of the glance duration by display locations.

	Driving		Stopped	
	Instrument cluster	Center console	Instrument cluster	Center console
Number of glances	475	497	317	349
Mean duration (sec)	1.25	1.21	1.62	1.64
Median duration (sec)	0.73	0.80	0.87	0.87
First quartile (sec)	0.49	0.47	0.50	0.55
Third quartile (sec)	1.44	1.33	1.63	1.80

(3) Gender

The glance duration was significantly different for men and women ($F(1, 1638) = 24.904$, $p \leq 0.001$). Female drivers looked 0.13 sec longer than male drivers while driving, and 0.24 sec longer than male drivers while they were stopped at intersections. Even though this experiment was carried out with only a small number of drivers, this difference was significant ($F(1, 1638) = 12.995$, $p \leq 0.001$). Table 7-2-3 shows the summary statistics of the glance-duration data by gender. The interaction between genders and display locations was significant in a 2 x 3 analysis ($F(1, 1638) = 8.317$, $p \leq 0.001$).

Table 7-2-3. Summary statistics of the glance-duration data by gender.

	Driving		Stopped	
	Men	Women	Men	Women
Number of glances	401	571	265	401
Mean duration (sec)	1.16	1.28	1.44	1.76
Median duration (sec)	0.67	0.80	0.73	0.97
First quartile (sec)	0.40	0.53	0.47	0.53
Third quartile (sec)	1.33	1.40	1.43	1.83

7-3. Frequency of glances to look at the visual targets

(1) Driving states

The mean frequency to look at the visual targets was 0.39 Hz (standard deviation = 0.185), while drivers were driving on urban streets. While drivers were stopped at intersections, they looked at the visual target less often (0.31 Hz, standard deviation = 0.081). The difference between the mean frequency of glances while drivers were stopped at intersections and while they were driving on urban streets was 0.08 Hz, but they were not significantly different ($F(2, 32) = 2.778$, $p = 0.106$).

(2) Display locations

While drivers were driving on urban streets, the difference of the mean frequencies of glances to the visual targets was only 0.02 Hz between the two display locations. It was not significantly different ($F(1, 16) = 0.025$, $p = 0.875$). While drivers were stopped at intersections, the mean frequencies of glances was the same for the two display locations, and the difference of the frequencies between the two display locations was not significant ($F(1, 16) = 2.778$, $p = 0.106$). The standard deviations of glance frequency for the center-console location were greater than for the instrument-cluster location's in both driving states. When drivers were driving, the mean frequencies were higher than stopped at intersections, however, the differences were not significant for each display location. No significant interaction was observed between display locations and driving states ($F(2, 16) = 0.882$, $p = 0.462$). Table 7-3-1 shows the summary statistics of the frequency of glances to the visual targets.

Table 7-3-1. Summary statistics of the frequency of glances to the two different display locations (8 drivers).

	Driving		Stopped	
	Instrument cluster	Center console	Instrument cluster	Center console
Mean frequency (Hz)	0.38	0.40	0.31	0.31
Standard deviation (Hz)	0.16	0.22	0.07	0.10

(3) Gender

While drivers were stopped at intersections, female drivers looked at the visual target less often (0.05 Hz) than male drivers, even though female drivers looked more often (0.12 Hz) than male drivers while they were driving on urban streets. The male drivers' mean frequencies to look at the visual target were the same in the two driving states. However, the gender difference was not significant in the analysis of variance ($F(1, 16) = 0.597$, $p = 0.446$). The interaction between genders and driving state was not significant ($F(2, 16) = 2.213$, $p = 0.109$), and the interaction between genders and display location was also not significant ($F(2, 16) = 0.306$, $p = 0.821$). The effect of gender difference did not interact for display locations. Table 7-3-2 shows the summary statistics of the frequency of glances for each gender.

Table 7-3-2. Summary statistics of the frequency of glances by driving states and gender.

	Driving		Stopped	
	Men	Women	Men	Women
Mean frequency (Hz)	0.33	0.45	0.33	0.28
Standard deviation (Hz)	0.17	0.19	0.09	0.07

7-4. Percentage of time that drivers look at the visual targets.

(1) Driving states

Drivers looked at the visual target 19.0 percent of the time in their mean, while they were driving on urban streets. The standard deviation of the percentage of time that drivers looked at the visual targets was 10.50 percent. While drivers were driving on urban streets, they looked at the visual targets smaller percentage than while stopped at intersections (-16.0 percent in the mean), and the standard deviation was also 4.58 percent smaller. The difference between the two driving states was not significant ($F(1, 32) = 0.628$, $p = 0.434$).

(2) Display locations

The difference of the percentage of time that drivers looked at the visual targets was not significant between two display locations ($F(1, 16) = 0.003$, $p = 0.955$), nor between the driving states ($F(1, 16) = 0.628$, $p = 0.434$). Drivers looked at the visual target at the instrument cluster 19 percent of the time, while they were driving on urban streets, and 18 percent at the center-console location. The standard deviations were similar: 10.2 percent to the instrument cluster and 11.4 percent to the center-console locations.

While drivers were stopped at intersections, the mean percentages of time that they looked at the visual targets were 15.8 percent to the instrument-cluster location, and 16.3 percent to the center-console location. The mean percentages to look at the two display locations were smaller than while drivers were driving on urban streets. However their differences were not significant for display locations. The interaction between display locations and driving states was not significant in a 2 x 2 analysis ($F(2, 16) = 0.211$, $p = 0.888$).

(3) Gender

Female drivers looked at the visual target a greater percentage of time than did male drivers. In both driving states, their difference was significant ($F(1, 16) = 2.899$, $p = 0.099$). There was no major difference between the standard deviations between genders. Table 7-4-1 shows the summary statistics of the percentage of time that drivers looked at the visual targets in each gender.

While drivers were stopped at intersections, both male and female drivers looked shorter percentages of time than while they were driving on urban streets. Their percentages were not significantly different between two driving states. No significant interaction was observed between gender and display locations ($F(2, 16) = 0.926$, $p = 0.441$) nor genders and driving states ($F(2, 16) = 1.144$, $p = 0.0.348$).

Table 7-4-1. Summary statistics of the percentage that drivers looked at the visual targets by driving states and gender.

	Driving		Stopped	
	Men	Women	Men	Women
Mean percentage (%)	16.0	21.0	13.1	18.9
Standard deviation (%)	10.6	10.5	7.83	6.56

7-5. Vehicle speed

The mean vehicle speed on urban streets was 7.6 mph (12.2 km/h). The standard deviation was 7.06 mph (11.30 km/h).

Details of the data analysis concerning the drivers' vehicle operations are described in Appendices 9, 10, and 11.

8. Conclusions

8-1. Effect of the three display locations on drivers' visual behavior

(1) Visual angle and viewing distance

The results of these experiments show that display location did not affect drivers' visual behavior as much as was hypothesized. The visual angle to the display did not seem to highly affect drivers' glance behavior because the differences among the three display locations were small and their correlation was weak. Similar to the relationship between the visual angle and the median glance duration, this relationship also was weak. The difference between the longest and shortest median glance duration was 0.05 sec.

In this experiment, the median glance durations for the three displays were similar. However, the glance durations to the HUD varied in a wider range than the other two locations. Furthermore, drivers looked at the HUD location less often than the other locations. These results suggest drivers' glance behavior relative to the HUD differed from the other two locations. HUDs are considered to be the displays that can reduce drivers' eye movements, because of their closer location to the center of the drivers' visual field. In this experiment, drivers looked at the HUD for shorter durations than the center console, even though the reduced eye movements would allow a longer viewing duration

The visual target for the HUD location was installed on the front windshield, and it had a different focal distance from its surrounding background. The other visual targets were installed on non-transparent surfaces, and they had the same focal distance as their surrounding backgrounds. For these two locations, drivers did not have to adjust their focal distance after their eyes were fixated in the general area around the visual targets. On the other hand, drivers had to be able to focus only on the HUD target, even though its surrounding background had a longer focal distance. This focusing process might be a reason that the glance duration to the HUD had a wider dispersion.

In this experiment, the visual target for the HUD location was installed on the front windshield, 0.9 meter (m) from the drivers' eyes. Okabayashi, Sakata, Furukawa, and Hatada (1993) stated that drivers rated the HUD image the least uncomfortable when it was projected 2.5 m forward, and the legibility of the images was improved when they were projected at further distance. They concluded the main effect of projecting information on the HUD location might be that drivers could look at the information in their peripheral view before they look at it in the central field of view. However, when complicated information, for instance a map, is presented on the HUD location, the effect of the information perception in the drivers' peripheral view might be different. Small eye movements might not be a main advantage of HUDs, and the location of HUDs should be carefully selected, considering the interference of road scenes behind the HUD images.

(2) Road types

The duration and frequency of glancing at displays can be used to identify a measure of drivers' attention to the displays, because drivers have to estimate the duration of a glance to the display by monitoring the traffic before each glance. The results of this experiment show that drivers' glance duration and frequency were different between two classes of driving states roads: (1) while driving on expressways, rural roads, and urban streets, and (2) while driving on suburban streets and while stopped at urban intersections. On first type of roads, the drivers' glance durations and the frequencies to the three display locations were statistically different, however their glance behaviors were similar on the second type of roads. Therefore, those two types of roads were considered to require different levels of attention for looking at the displays. Figure 8-1-1 shows the median glance duration that drivers looked at the three display locations on the different road types.

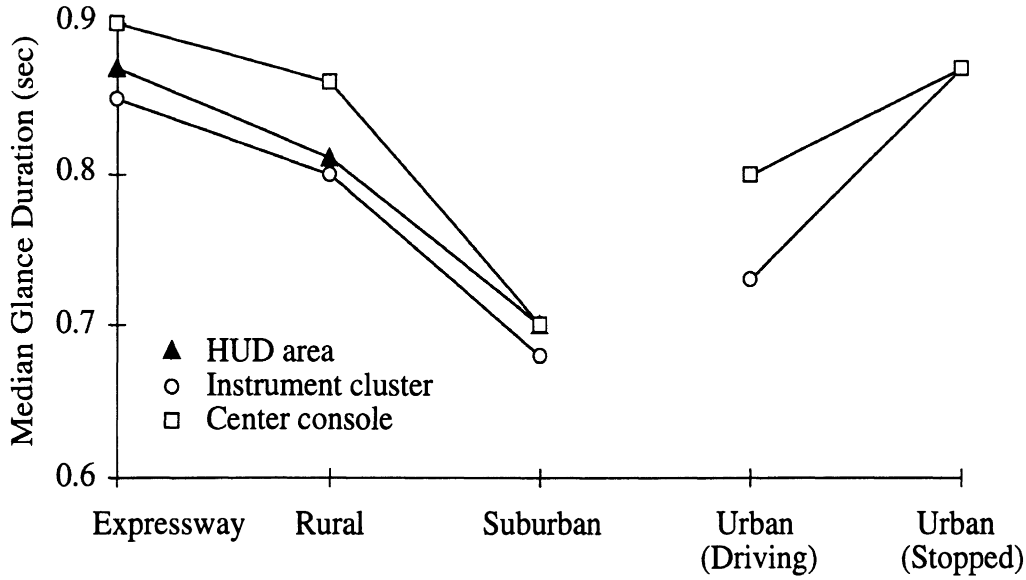


Figure 8-1-1. The median glance duration that drivers looked at the three display locations on different road types.

While driving on expressways and rural roads, drivers were able to gaze at the displays more often and for longer durations than on suburban streets. Therefore, the attentional demand required to monitor the traffic was considered to be similar on these two road types, and was lower than driving on suburban streets and being stopped at urban intersections. When drivers were not required to spend much attention for monitoring the traffic, they were able to pay more attention to each display.

Driving on urban streets seemed to have a high attentional demand, however drivers looked at the displays more often than expressways and rural roads. Even though the traffic on the urban streets was congested, the traffic was moving at low speed, and drivers might be able to spend more attention to look at the displays. The same as with the expressways and rural roads, drivers looked at the center-console location longer than the instrument-cluster location (data for the HUD location was not available because of the limitation of the measuring instruments). Consequently, the top of the center-console location seems to be the most appropriate place to install in-vehicle displays when the traffic conditions allows drivers to spend much attention to look at them.

While drivers were not looking at the visual targets on the three in-vehicle display locations, their attention was directed toward the other tasks that might be related to driving. On suburban streets and while stopped at urban intersections, the attentional demand required to monitor the traffic was relatively higher than it was on the other road types because drivers were able to look at the displays less frequently than they were on the other types of road. Under this condition, drivers' glance behavior did not differ among the three display locations.

8-2. Effect of drivers' age and gender

Younger drivers looked at displays longer and more often than the older drivers in many situations. Therefore, designers of in-vehicle displays should consider this when important and urgent information is presented for drivers.

Both age groups looked at the instrument cluster and the center-console locations for similar durations. However, the younger drivers looked at the HUD location longer than did older drivers. Glance duration was similar in both age groups while they were driving on expressways and suburban streets. On the other hand, older drivers looked at the displays for a shorter duration than younger drivers. Therefore, in-vehicle display system should accommodate between two age groups, especially on the rural roads.

Female drivers looked at displays more frequently than did male drivers. Female drivers also looked longer than male drivers while they were driving on urban streets. However, the difference due to gender was small on the other road types.

8-3. Drivers' visual attentional capability on different road types

Several criteria for the duration of the information on in-vehicle displays can be set, based on the identified limitations of drivers' visual behavior to look at displays while driving. These criteria are based on the road types because the results of this study showed that the road types affected the drivers' visual behavior more significantly than the display locations.

When designing information for in-vehicle display systems, the duration to present the information, and its complexity, should be considered. If information, such as a warning, is required to be recognized immediately, the information should be as simple as drivers can recognize in one glance. In this study, drivers' glance duration to displays, while driving on the public road, was measured. These durations represent the maximum amount of time that drivers felt they could safely glance at the targets. For example, 95 percent of the time, all drivers were able to look at the displays for at least as long as 0.33 sec, while driving on an expressway. This is the fifth percentile duration of the all glances on expressways. The fifth percentile durations for all road types are shown in Table 8-3-1. Based on the road type, if information can be understood within the durations shown in Table 8-3-1, then 95 percent of the time, all drivers will be able to read it within one glance.

If a message can be presented for longer than the duration of one glance, it should be long enough to be seen after the glance interval. This study measured the frequency of the glances at the displays. The results showed the second glance occurred within 5.68 sec after the first glance, 95 percent of the time. This is the 95 th percentile value of the intervals of all glances on expressways. Therefore, messages do not have to be presented for longer than this interval. Otherwise, their mean interval of glances was 2.94 sec on expressways. Therefore, the duration to present messages on expressways can be set, based on this interval.

Table 8-3-1. Fifth percentile duration of all glances, and the mean and 95 th percentile value of the interval of all glances to the in-vehicle displays on five types of roads.

Road type	Glance duration (sec)	Interval of glances (sec)		Percentage (%)
	5 th percentile	Mean	95 th percentile	Mean
Expressway	0.33	2.94	5.68	38
Rural road	0.32	2.86	5.95	35

Suburban street	0.30	3.33	7.09	25
Urban street (driving)	0.27	2.56	12.20	19
Urban street (stopped)	0.27	3.23	5.43	16

When the complexity of the information is high, drivers might need several glances to recognize the information. The duration that drivers need to read the information while driving can be estimated by the results of this study. While driving on expressways, drivers looked at the targets 38 percent of the time. This is the mean percentage of the time that drivers looked at the targets while driving on expressways. If information needs 5 sec to be recognized by drivers, the information should be continuously presented for at least 15.16 sec on expressways, because drivers can look at it for only 38 percent of the time while driving on expressways. Table 8-3-1 shows the mean percentages of the time that drivers looked at the targets while driving on the five road types, and those values can be used for estimating the duration of the information presentation on each type of road.

Drivers' visual behavior when they look at the same location using multiple glances was identified in this experiment, however the effect of multiple glances at the same message was not determined. Therefore, these criteria concern only the time limitation that drivers can look at the displays in a glance. Wierwille, Antin, Dingus, and Hulse (1988) measured the durations to accomplish many different tasks while driving on the public road. For example, drivers in their study needed 3.58 sec to determine their direction on a navigation system, but they looked at it for 1.30 sec (mean duration) in a glance and 2.76 times (mean number of glances). In addition, those drivers needed more than one glance to accomplish each task in their study. If the information is modified as that drivers can determine the direction of the vehicle within approximately 0.3 sec, drivers might be able to look at it in a glance.

Vitu and O'Regan (1991) determined the duration to read words in their study. Their test participants looked at the different length of words (five to nine letters) for different glance durations. Also, the reading duration varied by the first, eye-fixation location in the word. When the first eye fixation was on the center of the words, their glance duration was approximately 0.34 to 0.40 sec. If words for in-vehicle display systems are carefully selected to be recognized within 0.33 sec while driving on expressways, then drivers are able to look at the word in a glance.

The results of this experiment concerned the duration and the frequency of glances to the visual targets identified the road type affected the drivers' visual attention to the targets rather than their locations in the drivers' view. This experiment was carried out on five road types, at constant speed. Because all mean speeds were different, the type of roads can be estimated from that means. In addition, several criteria for the duration of information on in-vehicle displays were set, based on drivers' visual attention capability on different roads determined in this experiment. Consequently, this experiment identified the drivers' attention to the in-vehicle displays, and also developed the methods to define appropriate duration to present information on in-vehicle displays.

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Appendix 1. Official Consent Form of the Main Experiment

[printed on UMTRI letterhead]

Driver's Visual Behavior

Participant Consent Form

We are conducting a study concerning driver visual behavior and the influence of various traffic conditions. Data from real drivers, such as you, will help identify the best way to show information presented on instrument panels.

This experiment consists of a one hour drive to Canton, Michigan (Plymouth Rd, Ford Rd, Sheldon Rd, and M-14).

While driving in the instrumented vehicle on the public road, you will be asked to look at three targets as long as and as often as you feel safe to do so.

During the experiment, you will wear the eye camera to record the diameter of your pupil.

The experiment should take about 1.5 hours, for which you will be paid $25.00. If you have any problems or feel any discomfort while completing this experiment, you can withdraw at any time. You will be paid regardless.

Please obey all traffic laws while driving.

I have read and understand the information above.

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

Appendix 2. Biographical Form

University of Michigan Transportation Research Institute
Human Factors Division

Driver's Visual Attention Biographical Form

Subject: ____________

Date: ____________

Name: ______________________________

Male   Female (circle one)   Age: __________

Occupation: ____________________

What kind of car do you drive the most?

year: ________ make: ____________ model: ________

Annual mileage: ____________

How familiar are you with the test route ? (refer test route map)

very unfamiliar	moderately unfamiliar	neutral	moderately familiar	very familiar

Titmus Vision: (Landolt Rings)

Vision Correction: Yes (Eye Glass, Hard Contact Lens, Soft Contact Lens) , No

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

Appendix 3. Instructions for the Main Experiment

(Bold : experimenter's instruction to the participants)

Driver's Visual Behavior
Main Experiment Instructions

Before first test of the day , check all systems at morning

Before subject arrives; Check procedure and Instruments.

1. Prepare these sheets

- ❑ Pilot test A-1 Instruction
- ❑ Participant Consent Form
- ❑ $25 & Payment Form (2 Types)
- ❑ Biographical Form

2. Prepare these materials

- ❑ U of M ID
- ❑ Video Cassette
- ❑ Emergency Kit

When Subject Arrives

Hi, are you ____________? (use subject's name)
I'm__________(experimenter's name).
Thanks for coming, let's go down to the conference room.

Take subject down to the conference room and be seated.

The purpose of this experiment is to determine the driver's attentional demand at the various traffic conditions.

This study will take about a one and half hours to complete, and you'll be paid $25.
It involves a test drive around Ann Arbor area (show the test route map to the subject and explain it).

(An example,: we will take Plymouth Rd, Ford Rd, Sheldon Rd M14 and back to UMTRI by US23. The experiment will be started from this intersection.)

You do not have to worry about memorizing the route, I will suggest you what you should do at each moment.

During this experiment, you will wear the eye camera. That measures the diameter of your pupil. So, if you have any questions, please ask me at anytime. During the experiment, if you feel uncomfortable at anytime in the experiment, please let me know and we can stop it. Before we start, there is some paper work to complete. Please read and sign this official consent form, which basically repeats what I just said.

Have subject read and sign the consent form.

Also, we need to know a little more about you.

Check subject's driver's license (write it down to the biographical form)

Would you show me your driver's license, please.

Go through Biographical form with subject and fill in the appropriate answers.

Now we can check your vision.

Turn on both eye switches on the vision test device, slide 1. Adjust the height of the vision test device for the subject. Make sure subject wears any vision correction.

Please look at the first diamond, that the top circle is complete, but the other three (on the right, left, and bottom) are broken.
Can you tell me which circle is complete in the second diamond? The third?...

Prompt the subject until she / he has missed two in row. Record the last number answered correctly on the bottom of the biographical form, and note if corrective lenses are worn. Take subject to the test vehicle.

Explain systems to subject (on the way to test vehicle; High Bay)

Now, we'll go downstairs to the test vehicle.
The test vehicle is a Honda Accord and some additional equipment has been installed in it. There are no modifications to the engine, steering, or any other components. So, you should not notice any difference in the way of driving.

Explain systems to subject (at the test vehicle)

This is our test vehicle.
Please sit down in the driver's seat and adjust the seat as you like.

Wait few moments until subject finishes adjusting seat & steering wheel positions.

OK? You can see three dots in front of you. They are visual targets. During the experiment, you will be asked for looking at one of them, as often as and as long as you feel SAFE to do so. I will say this, "please look at the red dot as often as and as long as you feel safe to do so". Then, please look that as long as and as often as you feel safe to do so. When we arrived to the test section, I will put the eye camera on you.

Transportation to starting point

Please start the engine. Please wait a minute, I will start all the instruments.
Please adjust those mirrors and try to learn how to operate these switches. This red light on the tachometer is the "air bag warning light". We disconnected the air bag system, because it's dangerous if air bag is worked. Also this "cruise control" switch does not work.

OK! All systems are ready to go!
Are you ready to go?

OK! Let's go!

On Ford Rd.(Plymouth Rd)

Turn right. Please stop at Stop sign and turn right to Huron parkway. Please turn right on Plymouth Rd, and keep straight ahead until Ford Rd, it's about 3 miles. Keep going straight (some intersections) Please stop at that broad shoulder. I'll put the eye camera on you.

On Ford Rd

Let's start the experiment.
"Please look at the red dot as often as and as long as you feel safe to do so".

Tell subject to look at each dot about each 2'30" or 3' long.

OK, thank you, we finished this section.
Let's go to the next one.

During the test route

Suggest the direction at each intersection for the subjects. At major turn (change road), instruct the subjects about how long subjects will keep going straight. Keep checking the traffic around the test vehicle.

Arrive at UMTRI

OK, we're all done here. You can get out of the car now.

At the conference room

Thank you!
We just need to finish up the paperwork for your payment and we'll be done.

At the conference room, give participant the appropriate payment form. Show them the parts to fill out.

Make sure paperwork is filled out properly, and pay the subject (if not University employee). Otherwise tell participant that the amount will be on their next paycheck. Thank the participant and walk them back out to the third elevator of UMTRI.

Appendix 4. Official Consent Form of the Additional Experiment

[printed on UMTRI letterhead]

Driver's Visual Behavior

Participant Consent Form

We are conducting a study concerning driver visual behavior and the influence of various traffic conditions. Data from real drivers, such as you, will help identify the best way to show information presented on instrument panels.

This experiment consists of a one-hour drive in downtown Ann Arbor, Michigan (Beaks Rd, S. Main, E. William, State, Liberty, and Division Streets).

While driving in the instrumented vehicle on the public roads, you will be asked to look at one of the three targets as long as and as often as you feel safe to do so The experiment should take about 1.5 hours, for which you will be paid $15.00.

If you have any problems or feel any discomfort while completing this experiment, you can withdraw at any time. You will be paid regardless.

Please obey all traffic laws while driving.

I have read and understand the information above.

Print your name	Date
Sign your name	Witness (experimenter)

Appendix 5. Instructions for the Additional Experiment

(Bold: experimenter's instruction to the participants)

Driver's Visual Behavior
Additional Experiment Instructions

Before first test of the day , check all systems at morning

Before subject arrives; Check procedure and Instruments.

1. Prepare these sheets

- ❑ Pilot test A-1 Instruction
- ❑ Participant Consent Form
- ❑ $20 & Payment Form (2 Types)
- ❑ Biographical Form

2. Prepare these materials

- ❑ U of M ID
- ❑ Video Cassette
- ❑ Emergency Kit

When Subject Arrives

Hi, are you __________? (use subject's name)
I'm_________(experimenter's name).
Thanks for coming, let's go down to the conference room.

Take subject down to the conference room and be seated.

The purpose of this experiment is to determine the driver's attentional demand of various traffic conditions.

This study will take about a one and half hours to complete, and you'll be paid $15.
It involves a test drive in downtown Ann Arbor
(show the test route map to the subject and explain it).

You do not have to worry about memorizing the route, I will suggest you what you should do at each moment.

So, if you have any questions, please ask me at anytime. During the experiment, if you feel uncomfortable at anytime in the experiment, please let me know and we can stop it. Before we start, there is some paper work to complete. Please read and sign this official consent form, which basically repeats what I just said.

Have subject read and sign the consent form.

Also, we need to know a little more about you.

Check subject's driver's license (write it down to the biographical form)

Would you show me your driver's license, please.

Go through Biographical form with subject and fill in the appropriate answers.

Now we can check your vision.

Turn on both eye switches on the vision test device, slide 1. Adjust the height of the vision test device for the subject. Make sure subject wears any vision correction.

Please look at the first diamond, that the top circle is complete, but the other three (on the right, left, and bottom) are broken.
Can you tell me which circle is complete in the second diamond? The third?...

Prompt the subject until she/he has missed two in row. Record the last number answered correctly on the bottom of the biographical form, and note if corrective lenses are worn. Take subject to the test vehicle.

Explain systems to subject (on the way to test vehicle; in the High Bay)

Now, we'll go downstairs to the test vehicle. The test vehicle is a Honda Accord and some additional equipment has been installed in it. There are no modifications to the engine, steering, or any other components. So, you should not notice any difference in the way of driving.

Explain systems to subject (at the test vehicle)

This is our test vehicle. Please sit down in the driver's seat and adjust the seat as you like.

Wait few moments until subject finishes adjusting seat & steering wheel positions.

OK?
You can see three dots in front of you. During the experiment, you will be asked for looking at one of them, as often as and as long as you feel SAFE to do so. I will say this, "*please look at the red dot as often as and as long as you feel safe to do so*". Also, please continue it while stopped at intersections.

Transportation to starting point

Please start the engine. Please wait a minute, I will start all the instruments.
Please adjust those mirrors and try to learn how to operate these switches. This red light on the tachometer is the "air bag warning light". We disconnected the air bag system, because it's dangerous if air bag is worked.

OK! All systems are ready to go!
Are you ready to go?

OK! Let's go!

On Plymouth Rd to the parking area next to AMOCO. gas station

Turn right. Please stop at Stop sign and turn right to Huron parkway. Please turn left on Plymouth Rd, and keep straight ahead until Main street. It's about 3 miles. Keep going straight (some intersections). Please turn left on Main street. Please keep going straight until William. Please turn left on William.

Introduce the test route

We will drive the route once. This is the starting point, and you will be asked to look at the one of the visual targets as often as and as long as you feel safe to do so. Then please keep it during the drive, also stopping at intersections. Please keep going straight until we will hit State. Please turn left on State. Please turn left on Liberty. Please turn left on Main again. This is our route and we will drive it three times. Please turn right and stop at the parking.

Put the eye camera on the subject

At the parking area.

Now, we can start the experiment.

I will try to watch the traffic carefully, but, please be careful about other cars, pedestrians, and bikes.

Please obey all traffic laws and drive safely.

OK! We can start. Please exit this parking area to William.
Please keep going straight on William until State street.

Let's start the experiment!
Please look at the green dot as often as and as long as you feel safe to do so.

During the test route

Suggest the direction at each intersection for the subjects. At major turn (change road), instruct the subjects about how long subjects will keep going straight. Keep checking the traffic around the test vehicle.

Arrive at UMTRI

OK, we're all done here. You can get out of the car now.

At the conference room

Thank you!
We just need to finish up the paper work for your payment and we'll be done.

At the conference room, give participant the appropriate payment form. Show them the parts to fill out.

Make sure paperwork is filled out properly, and pay the subject (if not University employee). Otherwise tell participant that the amount will be on their next paycheck. Thank the participant and walk them back out to the third elevator of UMTRI.

Appendix 6. Vehicle-Speed Data in the Main Experiment

(1) Display locations

The mean vehicle speeds were almost the same, when drivers looked at the three different display locations. The mean speed, while drivers looked at three visual targets, was between 47.5 mph (76.0 km/h) and 48.5 mph (77.6 km/h). The standard deviations were between 5.65 mph (9.04 km/h) and 6.04 mph (9.66 km/h). In addition, there was no significant difference among the vehicle-speed data while drivers looked at the three display locations ($F(2, 198) = 0.047$, $p = 0.954$).

(2) Road types

The mean vehicle speeds corresponded to the speed limit on each road. The mean speed on the suburban street was the slowest, and the mean speed on the expressway was the fastest. The standard deviation of the vehicle speed on the expressway was only 1.2 mph (1.92 km/h) and it was smaller than on the other two road types. Table A-6-1 shows the summary statistics of the vehicle-speed data. The differences among the three road types were significant ($F(2, 198) = 525.912$, $p \leq 0.001$).

Table A-6-1. Summary statistics data of the vehicle speed data on each road type.

	Road type		
	Expressway	Rural road	Suburban street
Mean vehicle speed : mph (km/h)	62.0 (99.2)	51.8 (82.9)	30.0 (48.0)
Standard deviation : mph (km/h)	1.2 (1.92)	5.7 (8.32)	4.4 (7.04)

(3) Interaction between display locations and road types

The interaction between display locations and road types was significant in a 3 x 3 analysis ($F(7, 198) = 129.412$, $p \leq 0.001$). However the differences among the display locations were small (Figure A-6-1).

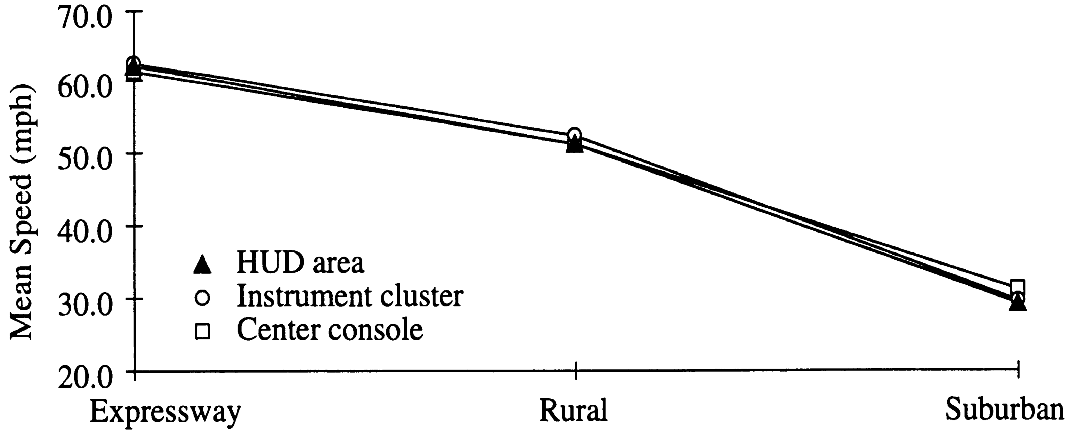

Figure A-6-1. Interaction between display locations and road types (1 mph = 1.6 km/h).

(4) Age and gender

The mean vehicle speed over all trials was 47.9 mph (76.6 km/h). The younger drivers drove faster (+2.9 mph = +4.6 km/h) than the older drivers. Vehicle speeds were not significantly different among both age groups ($F(1, 198) = 1.983$, $p = 0.161$) and genders ($F(1, 198) = 0.018$, $p = 0.895$). Also, age and gender did not have an interaction in a 2 x 2 analysis ($F(2, 198) = 0.738$, $p = 0.531$). The mean vehicle speeds were 48.2 mph (77.1 km/h) by male drivers and 48.0 mph (76.8 km/h) by female drivers.

(5) Interaction between display locations and age, and display locations and gender

No interaction was observed between display locations and age in a 3 x 2 analysis ($F(3, 198) = 0.438$, $p = 0.822$), and also between display locations and gender ($F(3, 198) = 0.137$, $p = 0.984$).

(6) Interaction between road types and age, and road types and gender

A significant interaction was observed between road types and age ($F(3, 198) = 232.059$, $p \leq 0.001$). The mean vehicle speeds of younger drivers were slightly faster than the older drivers' while they were driving on the rural roads and suburban streets. However, on expressways, younger drivers drove 4.6 mph (7.4 km/h) faster than older drivers. Even though the differences between genders were small, the interaction between road types and gender was significant in a 3 x 2 analysis ($F(3, 198) = 209.866$, $p \leq 0.001$). Figure A-6-2 shows their interactions.

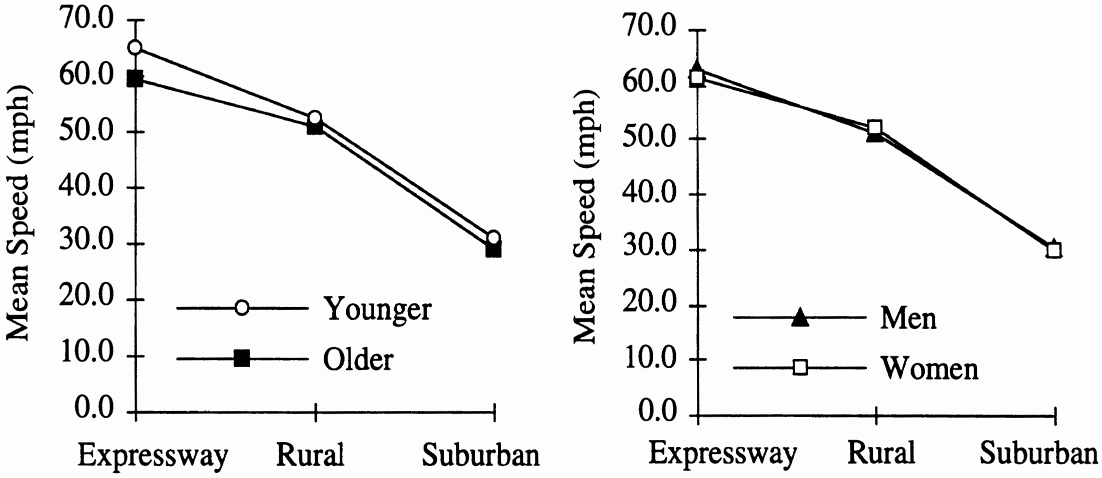

Figure A-6-2. Interaction between road types and age (left), and interaction between road types and gender (right). (1 mph = 1.6 km/h)

Appendix 7. Steering-Angle Data in the Main Experiment

(1) Display locations

The mean values of the steering-angle data were nearly 0 degrees in the three display locations. However, there was a small difference in their standard deviations. When drivers looked at the visual target on the center of the instrument cluster, the standard deviation of the steering angle was 5.7 degrees. But when they looked at the target on the center console, the standard deviation increased to 6.7 degrees. The result of a level-of-significance test showed no significant differences among the three display locations ($F(2, 198) = 1.500$, $p = 0.226$).

(2) Road types

The steering-angle data were influenced by the road curvature along the test route. The mean values of the three road types were nearly 0 degree. The expressway condition did not require operating the steering wheel over a wide range, because the standard deviation in that road was only 0.43 degree. Even though the suburban street was almost straight, it required operation of the steering wheel wider than the expressway (the standard deviation was 4.81 degrees). The rural road was also nearly straight, but there were a few gentle curves. In addition, drivers had to operate the steering wheel to compensate for the roughness of the road surface. Therefore, the rural road had the widest standard deviation (9.23 degrees). Steering angle on the expressway and the suburban street was not significantly different. However the standard deviation of steering angle on the rural road was significantly different from on the expressway and suburban street. Table A-7-1 shows the results of level-of-significance tests on the standard deviation of steering angle.

Table A-7-1. Results of level-of-significance test (F-test, and Scheffe's S test).

dependent variable = steering wheel angle				
Independent variable	Degrees of freedom	Sample size	F	p
Road types	2	198	5.027	0.007
Expressway vs. Rural roads	1	132	s	0.029
Expressway vs. Suburban streets	1	132	s	0.992
Rural roads vs. Suburban streets	1	132	s	0.021

(s = Scheffe's S test)

(3) Interaction between display locations and road types

A result of a 3 x 3 analysis concerned the standard deviations of steering-angle data showed a significant interaction between display locations and road types ($F(7, 198) = 2.686$, $p = 0.008$). Figure A-7-1 shows the interaction on the mean values of the standard deviation of steering angle. The figure shows a significant increase of the standard deviation, when drivers were driving on rural roads and they were instructed to look at the visual targets on the HUD area and the center console. On the other hand, the standard deviation on rural roads was smaller than on expressways while they were instructed to look at the visual target in the instrument cluster. However, there were only small differences among the three target locations while drivers were on expressways and suburban streets.

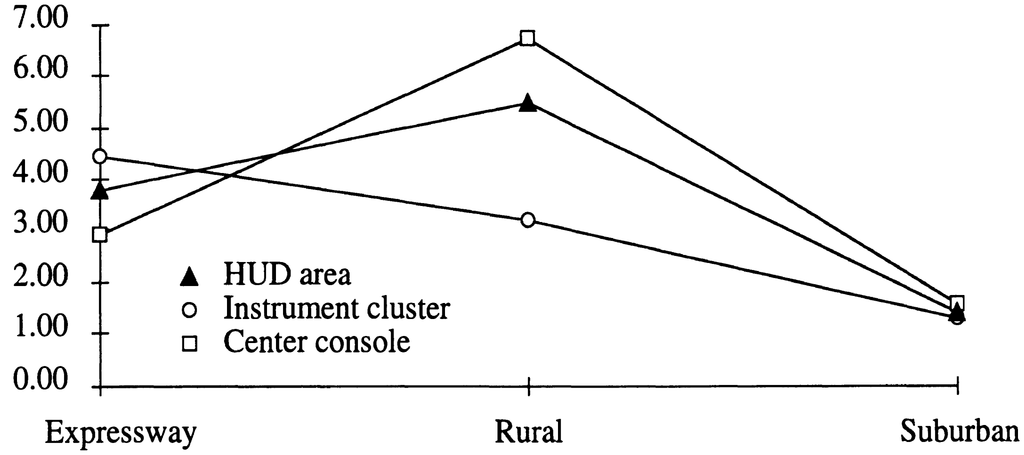

Figure A-7-1. Interaction between display locations and road types.

(4) Age and gender

The standard deviations of steering-angle data did not have significant differences between two age groups ($F(1, 198) = 0.011$, $p = 0.918$) nor gender ($F(1, 198) = 0.207$, $p = 0.650$). Also, their interaction was not significant ($F(2, 198) = 0.130$, $p = 0.942$). The standard deviation of younger drivers (2.2 degrees) was slightly greater than the older drivers' (0.9 degrees).

(5) Interactions between display locations and age, and display locations and gender

No significant interactions were observed between display locations and age ($F(3, 198) = 0.918$, $p = 0.470$), and the interaction between display locations and gender was not significant ($F(3, 198) = 0.653$, $p = 0.660$). In addition, the differences of standard deviation of steering-angle data were small (0.45 ~ 3.48 degree) between age groups and between genders.

(6) Interaction between road types and age, and road types and gender

The mean values of the standard deviation of steering-angle data showed that younger drivers had greater steering-wheel operations than did older drivers. Gender differences were small while they were driving on expressways and suburban streets. However, male drivers operated the steering wheel wider than female drivers. The interaction between road types and age was significant in a 3 x 2 analysis on the steering-angle data ($F(3, 198) = 2.061$, $p = 0.072$). Also, the interaction between road types and two gender was significant ($F(3, 198) = 2.312$, $p = 0.046$). Rural roads had the widest standard deviation in the three road types. Figure A-7-2 shows the interactions on the mean standard deviations between road types and two age groups, and between road types and two genders.

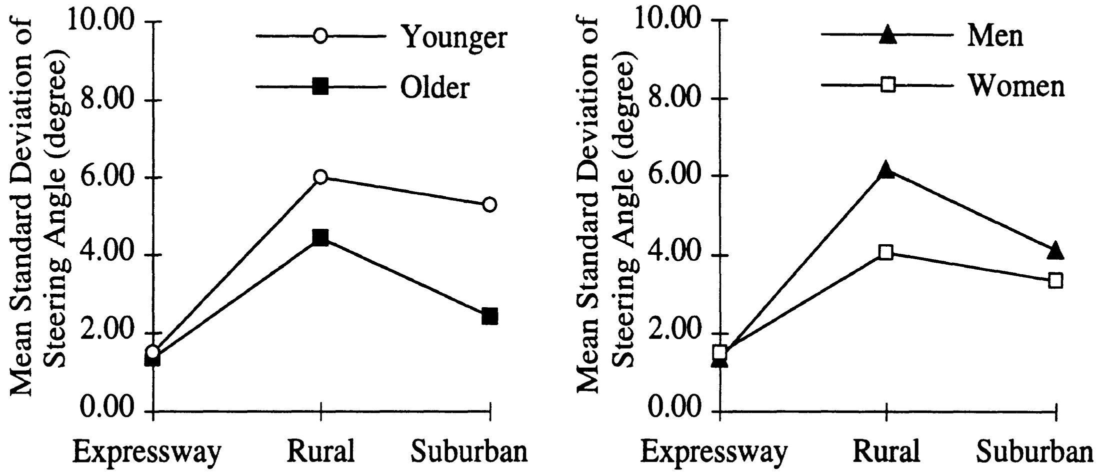

Figure A-7-2. Interaction between road types and age (left), and interaction between road types and gender (right).

Appendix 8. Throttle-Opening-Ratio Data in the Main Experiment

(1) Display locations

Similar to the result of the vehicle-speed data, the throttle-opening ratio data also did not show any significant differences among the three display locations ($F(2, 198) = 0.170$, $p = 0.844$). The mean throttle opening ratio was between 8.6 and 8.9 percent, and the standard deviations were between 2.34 and 2.69 percent.

(2) Road types

The mean throttle opening ratios had a strong correlation with the mean vehicle speeds (the correlation efficiency = 0.998). The standard deviation of the throttle opening ratio shows the magnitude of correctional operation of the acceleration pedal, however this test route did not require wide throttle operations for drivers, the standard deviations of throttle opening ratios on each road type were small. Figure A-8-1 shows the correlation between the mean vehicle speed and the mean throttle opening ratio. Table A-8-1 shows the summary statistics of the throttle-opening-ratio data.

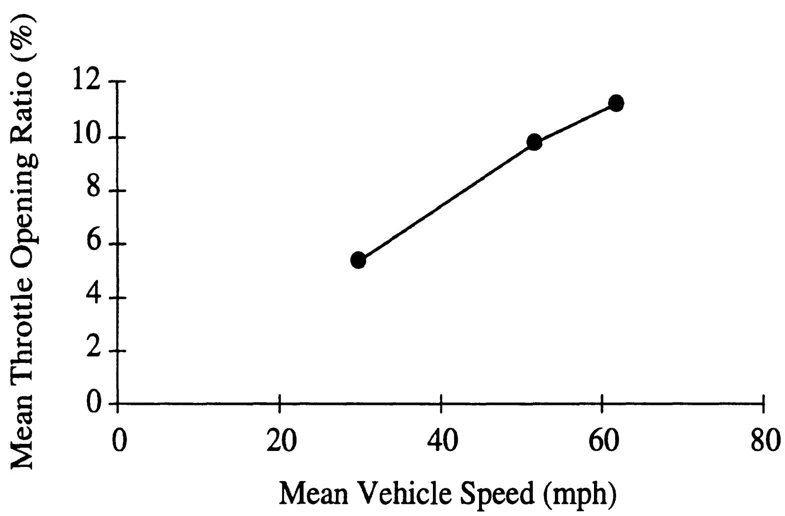

Figure A-8-1. Correlation with the mean vehicle speed; (1 mph = 1.6 km/h).

Table A-8-1. Summary statistics of the throttle-opening-ratio data (by road type).

	Road type		
	Expressway	Rural road	Suburban street
Mean throttle opening ratio(%)	11.2	9.7	5.3
Standard deviation (%)	2.2	2.7	2.2

(3) Interaction between display locations and road types

The interaction between display locations and road types was significant in a 3 x 3 analysis ($F(7, 198) = 56.504$, $p \leq 0.001$), and the differences among the test conditions were small. Figure A-8-2 shows the interaction between display locations and road types.

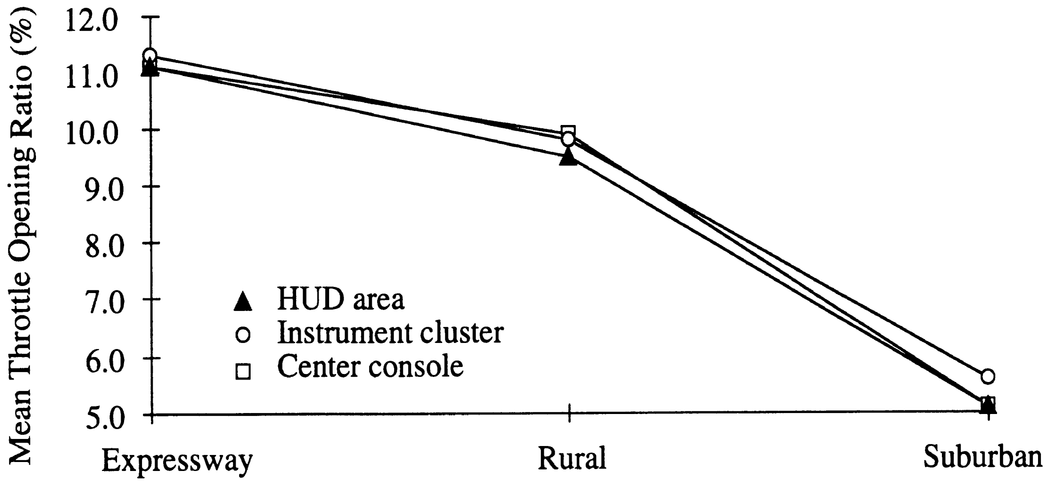

Figure A-8-2. The interaction between display locations and road types.

(4) Age and Gender

The younger drivers' mean throttle opening ratio (9.3 percent) was greater than the older drivers' (8.2 percent). The difference between two age groups was significant ($F(1, 198) = 6.397$, $p = 0.012$). The mean throttle opening ratio was the same (8.8 percent) for gender, but the female drivers' standard deviation (3.10 percent) was slightly wider than the male drivers' (2.82 percent). The data in the two genders were not significantly different ($F(1, 198) = 0.005$, $p = 0.944$). In addition, the interaction between the age and gender was not significant ($F(2, 198) = 2.113$, $p = 0.100$).

Appendix 9. Vehicle-Speed Data in the Additional Experiment

The mean vehicle speed on urban streets was 7.6 mph (12.2 km/h). The standard deviation was 7.06 mph (11.30 km/h).

(1) Display locations

While drivers were looking at the visual target in the instrument cluster, the mean vehicle speed was twice as high as when they were looking at the target on the center console location. This difference was not significant ($F(1, 16) = 0.891$, $p = 0.361$). Table A-9-1 shows the summary statistics of the vehicle speed data.

Figure A-9-1. Summary statistics of vehicle speed data by the different display locations.

	Instrument cluster	Center console
Mean vehicle speed; mph (km/h)	10.2 (16.3)	5.0 (8.0)
Standard deviation; mph (km/h)	7.14 (11.42)	7.00 (11.20)

(2) Gender

A difference was not observed in the vehicle speed data. The mean speeds were 7.9 mph (12.6 km/h) by male drivers, and was 7.2 mph (11.5 km/h) by female drivers. Their data were not significantly different ($F(1, 16) = 0.898$, $p = 0.359$). The standard deviations were 7.41 mph (11.86 km/h) in male drivers, and 6.72 mph (10.75 km/h) in female drivers.

Appendix 10. Steering-Angle Data in the Additional Experiment

The mean standard deviation of the steering angle was 51.4 degrees, because of turns at intersections and some merging along the test route.

(1) Display locations

The standard deviation of steering angle while drivers were looking at the visual target in the instrument cluster was 54.2 degrees. This was wider than while they were looking at the center-console location. The difference of the standard deviations was not significant ($F(1, 16) = 0.289$, $p = 0.599$).

(2) Gender

Mean standard deviations were 50.4 degrees by male drivers, and 52.5 degrees by female drivers. The difference between the standard deviations of each gender was not significant ($F(1, 16) = 0.702$, $p = 0.416$).

Appendix 11. Throttle-Opening-Ratio Data in the Additional Experiment

The mean throttle opening ratio was 2.2 percent through the experiment. The mean standard deviation of the throttle opening ratio was 3.7 percent.

(1) Display locations

No significant difference was observed in the throttle opening ratio between the times when drivers were looking at the visual targets on the instrument cluster and center console. The mean standard deviations were 3.63 percent while looking at the target on the instrument cluster, and 3.71 percent while looking at the another one. The difference was not significant ($F(1, 16) = 0.020$, $p = 0.891$).

(2) Gender

The mean throttle opening ratio was the same in both the male and female drivers (2.2 percent). The mean standard deviations were 4.00 percent in male drivers, and 3.34 percent in female drivers. The difference of the throttle opening ratio between two genders was not significant ($F(1, 16) = 1.987$, $p = 0.180$).