Driver Behavior While Operating In-vehicle Devices

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ABSTRACT

This paper presents results of two studies conducted to examine effects of different in-vehicle tasks on the drivers' visual and vehicle control behaviors. The first study was conducted in a fixed-base driving simulator, and the second study was conducted in an actual vehicle on public roads. The results obtained from the analyses of the data show following:

1) Task complexity significantly affected driver behavior as measured by number of glances, total visual time, total eye time, lane position variability and velocity changes while performing different in-vehicle visual tasks.
2) The number of glances made in performing various tasks was correlated with total visual time and total eye time. This suggests that the number of glances is a good measure to study future visual tasks for driver distractions.
3) Currently performed complex visual tasks associated with radios, climate controls and cell phones were generally completed within 6-8 glances and about 10-20 sec of total visual time.
4) Finally, the data on number of eye glances obtained in the driving simulator showed some similarity with the data obtained in actual driving situations.

INTRODUCTION

Over the past few years, a number of in-vehicle devices have been proposed and/or developed to provide the driver with many new features to improve communication, entertainment, convenience and safety. Addition of these devices can significantly increase driver's workload, and can distract the driver from performing the primary driving tasks (*1*). A number of studies using different methodologies are currently being conducted to develop guidelines to maintain the driver distractions within acceptable limits. In order to understand the effect of driving distractions, two studies were recently conducted by the ACE (Advanced Cockpit Enablers) Team formed under the leadership of Collins & Aikman and in collaboration with six other automotive suppliers (Sanyo FMS Audio Sdn. Bhd., Nippon Seiki International, Ltd., Douglas Autotech Corporation, Valeo Switch and Detection Systems, KSR International Company, and Alcoa Fujikura, Ltd.) and two universities (University of Michigan-Dearborn and Oakland University, Rochester, Michigan).

The ACE team developed a fixed-base driving simulator to support quick evaluation of automotive driver interfaces and integration of product development ideas. The team of suppliers can come up with economical systems based on new concepts and solutions. They also have developed ways to create physical working prototype versions of various driver interfaces with computer simulated functionality in a short time period. This driving simulator has reduced the time to evaluate these working prototypes, and thus, screen out a number of concepts within a few days. The ACE's entire evaluation process and the driving simulator are presented in more detail in references (*2, 3 and 4*).

OBJECTIVES

The objective of this paper is to present some basic relationships observed from the measurements of drivers' eye glance behavior and vehicle control performance while performing a number of tasks associated with the operation of different in-vehicle devices. The relationships also provide further understanding into the development of future glance based performance requirements to limit driver distractions in operating in-vehicle devices (*1*).

METHOD

A series of driving studies were conducted using the fixed-base driving simulator and an actual vehicle on public roads. During these studies drivers were asked to drive on rural roads in normal manner (at about 45 mph). During each study each driver drove six times (six laps) on a pre-selected route, and during each lap at 8 of the 16 pre-selected locations, the driver was asked to perform a given task involving operation of an in-vehicle device (involving one or more controls and displays). The driver's eye glances made during the performance of the in-vehicle tasks were video recorded and driving performance was measured by recording vehicle velocity and lane position.

STUDY 1: DRIVING SIMULATOR STUDY

Twelve drivers (8 males and 4 females, ages 16-48) participated in this first study. All the drivers had valid driver's license and normal vision (20/40 or better with necessary correction glasses). Figure 1 presents a picture of the driving simulator. A detailed description of the simulator is presented by Bhise, et al. (*3)* and Smid, et al. (*4*). The simulator included a reconfigurable buck with a large (11 feet wide) driving scene generated by a video projector driven by a Silicon Graphics computer with 24 degrees of freedom vehicle model. The road scene involved imagery of a two-lane rural winding road.

Procedure:

After familiarization with the vehicle controls and a 20-minute simulator driving (to familiarize with the simulator and test route), each driver drove six complete laps on the test course. Each lap consisted of an eight-mile rural 2-lane road, which took about 15 minutes to complete. Sixteen locations were pre-selected on the test route. In any given lap, the test drivers were asked to perform eight of the sixteen randomly selected in-vehicle tasks. The instructions for each of the sixteen tasks (described below) were recorded in voice files, which were played when a subject arrived at each pre-selected location. The tasks were arranged so that during each successive two laps (i.e. laps 1 and 2, laps 3 and 4, and laps 5 and 6), all the sixteen tasks were presented. Thus, by the time the drivers performed the tasks in laps 5 and 6, they had already experienced performing all the tasks (i.e. performing each task at least two times in the first 4 laps). All the 12 subjects performed exactly the same tasks, except half the subjects were tested with a production radio (referred as Radio 1) and other half used a prototype radio (referred as Radio 2) with similar functionality. Both the radios were mounted in the buck at the same location (as shown in FIGURE 1). The vertical angular location of the radio was at about 30 degrees from the driver's eyes (measured from the centroid of the eyellipse). Both Radio 1 (see FIGURE 1) and Radio 2 had a CD player (located higher up), a rotary volume control and six preset stations. The picture of Radio 2 was not included to maintain design confidentiality. The following instructions were provided through pre-recorded audio files at the initiation of each task:

Task 1: Press FM (push button) and select preset 6 (push button).
Task 2: Press CD (push button), eject CD in the radio, and insert the "Billboard Top Hits" CD.
Task 3: Press FM, listen to the first three presets, and then select the music of your choice.
Task 4: Adjust the bass and treble to your liking.
Task 5: What is the answer to the following math problem: Five plus nine, minus six, times twenty-three?
Task 6: Press CD, seek track 4.
Task 7: Press FM, tune to 95.5.
Task 8: Turn the volume up.

Task 9: Find the cell phone, and dial your home phone number backwards.
Task 10: Press FM, tune to 107.5.
Task 11: Turn the volume down.
Task 12: Press FM, tune to 93.1.
Task 13: Press FM, seek to 105.1.
Task 14: Press CD, seek to track 2.
Task 15: Press CD, eject the CD in the radio, and insert the "Paula Abdul" CD.
Task 16: Ring….Ring…..Ring (Answer the cell phone when it rings).
The cellphone used for Tasks 9 and 16 was kept on the front passenger's seat. The cellphone did not have a flipping door to access the keys. These two cellphone tasks along with Task 5 (requiring no visual involvement) were used as reference or control tasks.

Data Collection and Analyses:

The outputs of the simulator runs were recorded in computer database files. The files consisted of time and distance based values of lane position, velocity, pedal positions and steering wheel angle. In addition, the driver's face was videotaped using a digital video camera, which was synchronized with the simulator data. The eye glance data were reduced manually from the digital video files. The experimenter also kept track of any control operational errors (e.g. long looks at the controls, pushed wrong button, etc.) and erratic vehicle maneuvers (e.g. lane deviations, slowed down, etc.). The data were processed to obtain values of the following performance measures for each task performed by each subject in each lap.

Performance Measures:

<u>Number of glances</u>: Total number of glances made away from the forward road scene to perform a given task of operating an in-vehicle device.

<u>Total eye time</u>: Total time spent in glances made away from the forward road scene to perform a given task of operating an in-vehicle device. (Sum of eye glances in seconds)

<u>Total visual time</u>: Total time elapsed between the beginning of the first glance and the end of the last glance made in performing a task (measured in seconds).

<u>Lane (or lateral) position standard deviation</u>: Standard deviation of lateral position of the vehicle in lane (measured in meters) obtained from 90 lateral position data samples (which included: 5 samples/sec x 6-second time interval x 3 six-second intervals) over an 18-second interval measured from the location at which the verbal instruction was given to perform a task.

<u>Velocity standard deviation</u>: standard deviation of velocity (measured in m/sec) obtained from 90 velocity data samples (which included: 5 samples/sec x 6-second time interval x three 6-second intervals) over 18-second interval measured from the location at which the verbal instruction was given to perform a task.

Driving Performance Score: Number of erratic events in the 18-second interval (defined above). The events were considered erratic when: 1) The lane position standard deviation in any of the first three 6-second intervals (following the verbal instructions) exceeded 0.6 m, or 2) The velocity standard deviation in any of the first three 6-second intervals (following the verbal instructions) exceeded 1.8 m/sec.

Results of Study 1:

A spreadsheet containing the values of all the above performance measures for each task (performed by each subject in each location in each lap using each radio) was prepared and statistical analyses (analyses of variance, correlation and regression). The data were analyzed by using Minitab statistical data analysis software. The data collected in laps 5 and 6 are presented in this paper because of the practice effects were observed in earlier laps and to focus on key results. (Note that laps 1 and 2 performance was different [longer times], as compared to the laps 3 and 4, and laps 5 and 6). All the data collected in the simulator trials using the twelve subjects and two radios was aggregated to obtain the relationships described below. It should be noted that since the objective of this paper is to show some basic relationships in understanding driver behavior while operating in-vehicle devices, the data were analyzed for the effects of tasks by aggregating over subjects and radios. The analysis of variance (ANOVA) tests conducted on all the performance measures showed that the effects due to subjects and radios were statistically significant (at $p < 0.05$ or smaller). Thus, adding (or aggregating) the variability due to subjects and radios in the analyses described below provided a more robust character of the relationships.

Number of glances affected by task complexity. FIGURE 2 presents the means and 95% confidence intervals of number of glances made by the subjects (in the last two laps, i.e. laps 5 and 6) for each task. The ANOVA tests showed that the number of glances were significantly different (at $p<.05$) for different tasks. Figure 2 shows that lowest number of glances (away from the forward road scene) were made in tasks 5 (a math task— required no looks away from the road scene), task 8 (Turn volume up –using a traditional rotary volume control) and task 11 (Turn volume down). On the contrary, tasks 2 and 15 (CD ejection and insertion of a new CD), task 9 (cell phone dialing), and tasks 10, 12, and 13 (selecting FM band and tuning/seeking a station) required large number of glances. In general, the number of glances is directly related to complexity of the task (number of motions or steps involved in the acquisition of necessary visual information).

High Correlation of the Number of Glances with Total Eye Time and Total Visual Time. FIGURES 3 and 4 present means and 95% Confidence Intervals on Total Visual Time and Total Eye Time, respectively. These data, in general, support that complex tasks not only take more number of glances, but they also require greater total eye time and total visual time. FIGURES 5 and 6 show that the measure, number of glances, is strongly correlated and linearly related to both the total eye time and total visual time.

The key findings from the above data are:

1. Total number of glances is an excellent and a practical measure of visual complexity (or visual informational demand) in performing in-vehicle driving tasks. This finding is important because it is easier to simply count number of glances while reducing the data as compared to computing time based measures such as the total eye time and the total visual time.
2. Currently performed complex tasks (such as the radio tuning, CD changing, cell phone dialing) can be completed within about 8 glances and about 10-20 sec of total visual time.

Lane position standard deviation and velocity standard deviation. FIGURE 7 presents a correlation matrix of the glance based and the driving performance related measures in this study. The data showed that there were no significant correlations between the glance based and the driving performance measures (the lane position standard deviation, velocity standard deviation and the driving performance score). Further, ANOVA tests failed to show any significant effect due to differences in tasks on the lane position standard deviation and the velocity standard deviation. The lack of correlation (or weak correlation among several variables) appears to be due to the fixed-base nature of the driving simulator (where the driver does not get actual vehicle motion cues and he/she solely derives the information from visual cues from the driving scene and some road noise feedback). Further, the simulator steering system did not provide any increase in steering torque feedback or auditory feedback on tire squeal noise with the steering wheel movements.

STUDY 2: ACTUAL DRIVING ON PUBLIC ROADS

Six drivers (3 males and 3 females; ages 25-48) were asked to drive on a pre-selected test route with similar roadway characteristics as that used in the simulator and the same procedure was used in the previous simulator study. The following 16 tasks were included in the study. (Please note that tasks 1-4 and tasks 6-8 are the same as those in Study 1. Other tasks were added to include operations related to climate controls, wipers and power window operation.)

Tasks Used for the Drive Test:

Task 1: Press FM and select Preset 6
Task 2: Press CD, eject CD in the radio, and inset the “Billboard Top Hits” CD.
Task 3: Press FM, listen to the first three presets, and then select the music of your choice.
Task 4: Adjust the bass and treble to your liking.
Task 5: Imagine that your windshield is fogging up; quickly direct maximum air to defrost the windshield
Task 6: Press CD, seek track 4.

Task 7: Press FM, tune to 95.5.
Task 8: Turn volume up.
Task 9: Find the cell phone, and dial your home phone number.
Task 10: Lower the driver's window a little to get fresh air
Task 11: Turn the fan speed down.
Task 12: Increase temperature a little
Task 13: Turn on wipers at low speed
Task 14: Turn off the wipers
Task 15: Turn on the wipers at two settings above the lowest interval speed
Task 16: How much gas do you have?

The test was conducted using a 2002 Ford Taurus. FIGURE 8 presents a picture of the Radio (referred as Radio 3) and Climate Control Unit of the Vehicle. The eye glances, velocity and lane position data were recorded by using three separate video cameras. The velocity data was obtained by reading maximum change in velocity during the completion of the tasks from the speedometer recorded in the videotape. Similarly, the maximum lane deviation was obtained from the measurement of lateral distance of the left lane marking from a reference point on the vehicle (a point on the wiper) in the video recordings of the road scene.

Results of Study 2:

Number of Glances. FIGURE 9 presents means and 95% confidence intervals of average number of glances made by the subjects in this study. The data shows that Task 2 of changing a CD (ejecting and removing the CD in the radio, getting a new CD from a CD case, inserting it in the radio and placing the old CD in the case) was much more complex (required about 10-17 total number of glances). On the other hand, simple tasks (involving activation of a single control) such as task 1, 8, and 10-16 required only 1 to 3 glances.

Correlation between number of glances and driving performance measures. FIGURES 10 and 11 present relationships between the average number of glances with lane deviation and velocity change respectively, obtained in the driving test. These data show that under actual driving, the number of glances influenced the driving performance. The correlation coefficients for the relationships shown in the FIGURES 10 and 11 were 0.588 and 0.478, respectively.

Comparison between Study 1 and Study 2 results. First, the reader may recall that in Study 1, no significant correlations between the number of glances and the driving performance measures were observed. Whereas, in Study 2, Figures 10 and 11 showed significant (but somewhat weak) correlation of number of glances with lane deviations and velocity change (0.588 and 0.478, respectively). Further, a small but significant correlation (r=0.276) between the lane deviation and velocity change measure was observed in Study 2. Whereas, no significant correlation was observed between lane deviation and velocity standard deviation in study 1. The figure also shows that the

Driving Performance Measure was slightly more correlated (but statistically not significant) to the glance based measures as compared to the standard deviations of lane position or velocity. The Driving Performance Measure, however, had a statistically significant but weak correlation with the standard deviations of lane position and velocity.

FIGURE 12 shows comparison of average number of glances in the seven tasks that were similar between the two studies. The simulator data for one production radio that was similar to the radio in the vehicle used for the drive test is compared in this figure. The correlation between the number of glances in the simulator vs. the drive test was 0.411, thus suggesting some similarity in the glance behavior in the two conditions. However, the relationship was very weak (significance level $p = .3$).

DISCUSSIONS

There were two basic reasons in presenting this paper. One was to show that number of glances is a good measure of visual demand in performing the in-vehicle tasks. The measure was significantly affected by differences in tasks presented in both the driving simulator and actual driving tests. The second reason was to calibrate this measure in determining acceptable or allowable number of glances in operating various in-vehicle devices. The data on number of glances presented in Figures 2, 9 and 12 show that most simple tasks can be performed in less than 2-3 glances; and the complex tasks involving operating radios, CD players and climate controls take typically 3-8 glances. The highest average number of glances were required in the CD swapping task (Task 2) in the actual driving.

The comparison of the relationships of the number of glances with the maximum lane deviation (FIGURE 10) and change in velocity (FIGURE 11) obtained in the drive test with the lack of correlation between the number of glances and the driving performance measures in the simulator study (FIGURE 7) suggests the following: 1) A driver’s visual behavior in performing in-vehicle tasks are not substantially different in a driving simulator as compared to in actual driving conditions. 2) However, the driving performance in performing in-vehicle tasks in a fixed-base driving simulator can be significantly different from that in actual driving. In actual driving, while performing all the tasks, no subject intruded into either adjacent lane. But they slowed down considerably (over 5 mph) in performing more complex tasks (See FIGURE 11). Additional research involving improved driver feedback through enhanced steering and auditory feedback would help understand and minimize the observed differences between the driving performance measures in the simulator as compared to the actual driving conditions.

The data obtained in the two studies in this paper when compared with similar types of studies (discussed in *reference 1*) suggest that most currently performed complex visual tasks associated with radios, climate controls and cell phones (dialing and answering, but not continued conversation) are generally completed within about 6-8 glances and about

10-20 seconds of total visual time. On the other hand, tasks requiring more than 8 glances can create distractions that can lead to significant speed reduction (of 5 mph or greater—see FIGURE 11) and/or increase in lane deviation (FIGURE 10).

In 2002 TRB paper Bhise (1) suggested consideration of the following rules to evaluate visual distractions due to in-vehicle devices:

1. Three glances rule: operate an in-vehicle device in 3 glances and 10 secs. total (visual) time.
2. Five glances rule: operate an in-vehicle device in 5 glances and 16 secs. Total (visual) time.
3. Eight glances rule: operate an in-vehicle device in 8 glances and 25 secs. Total (visual) time.

The data presented in this paper, thus, support the three and five glances rules as reasonable to limit visual distractions. Clearly, much more research data in this area are needed before such performance rules can be implemented for future design on in-vehicle devices.

CONCLUSIONS

The data presented in this paper showed that task complexity significantly affected driver behavior as measured by number of glances, total visual time, total eye time, lane position variability and velocity changes while performing different in-vehicle visual tasks. The number of glances made in performing various tasks is a good measure to study future visual tasks for driver distractions. Currently performed complex visual tasks associated with radios, climate controls and cell phones were generally completed within 6-8 glances and about 10-20 sec of total visual time. Finally, the data on eye glances obtained in the driving simulator compared well with the data obtained in actual driving situations.

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LIST OF FIGURES

FIGURE 1 ACE Driving Simulator

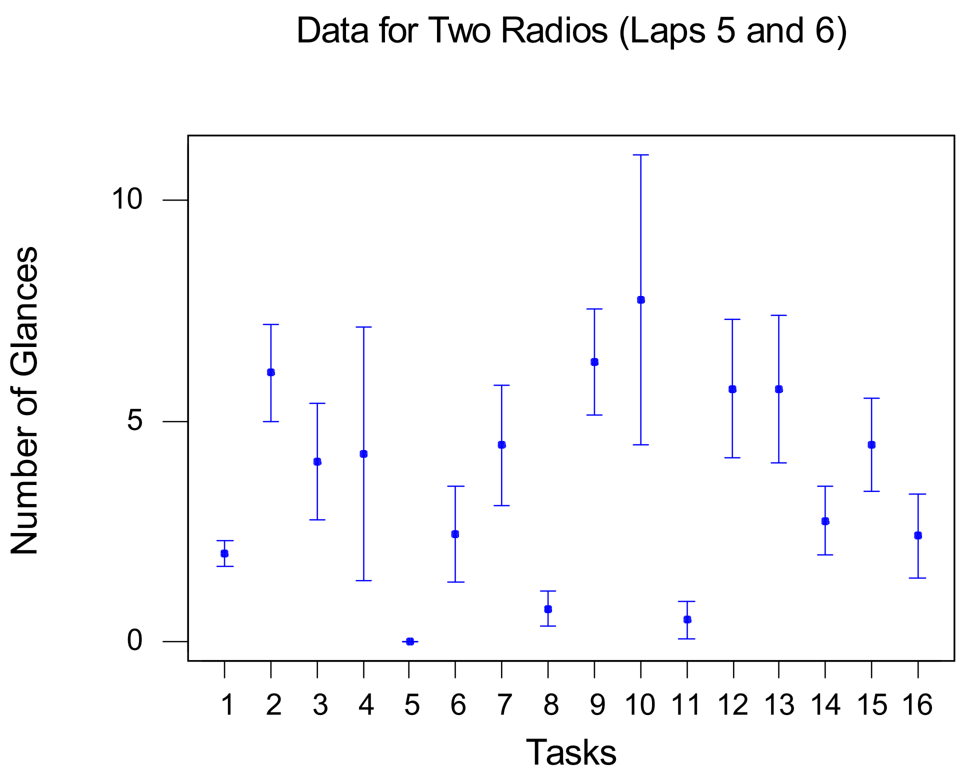

FIGURE 2 Means and 95%Confidence Intervals of Number of Glances (in the last two laps) Obtained in the Driving Simulator (Study 1)

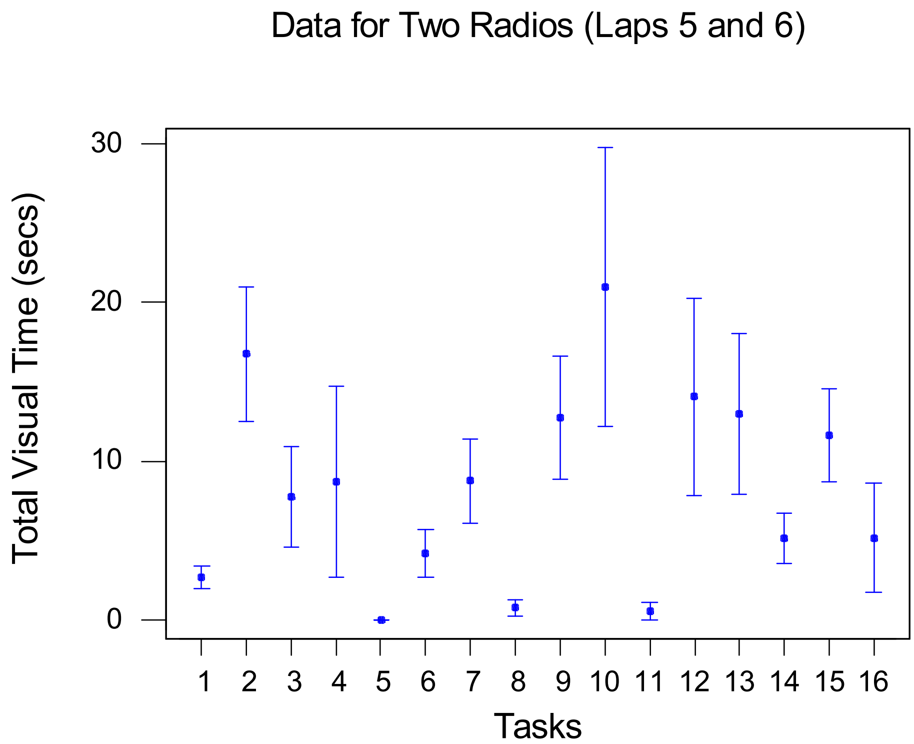

FIGURE 3 Means and 95% Confidence Intervals on Total Visual Time (in the last two laps) Obtained in the Driving Simulator (Study 1)

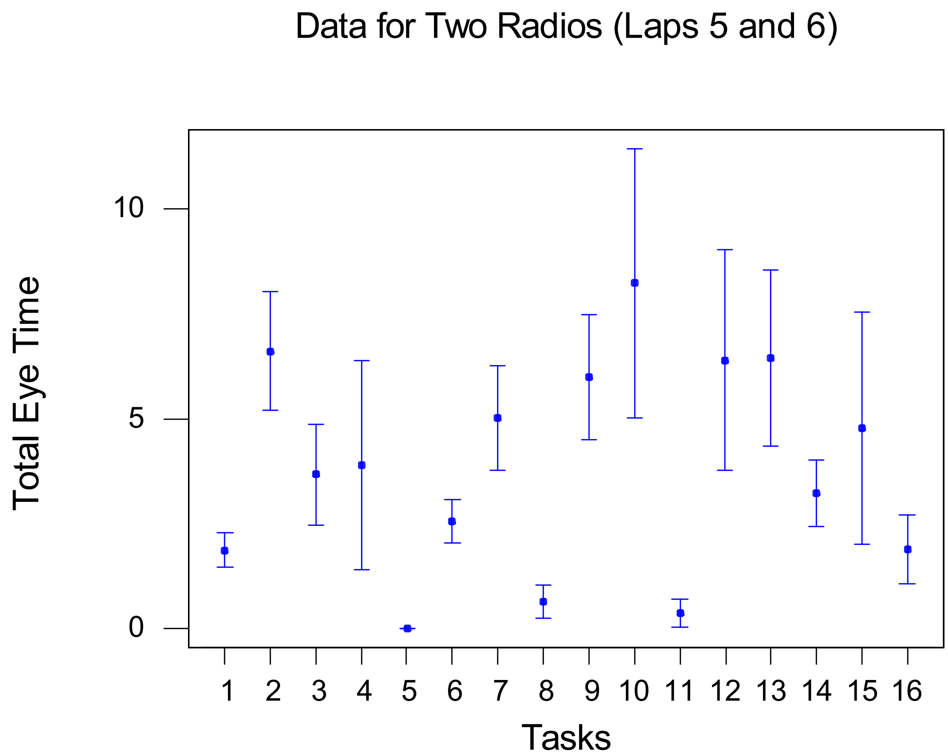

FIGURE 4 Means and 95% Confidence Intervals of Total Eye Time (in the last two laps) Obtained in the Driving Simulator (Study 1)

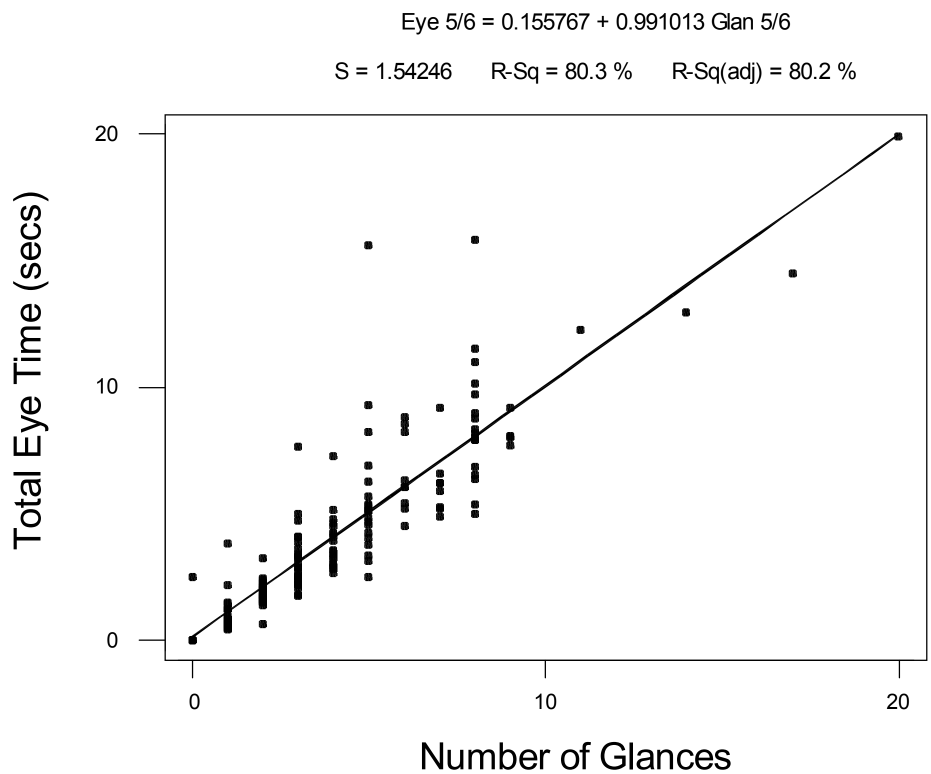

FIGURE 5 Relationship between Total Eye Time and Number of Glances Obtained in the Driving Simulator (Study 1 in Laps 5 and 6)

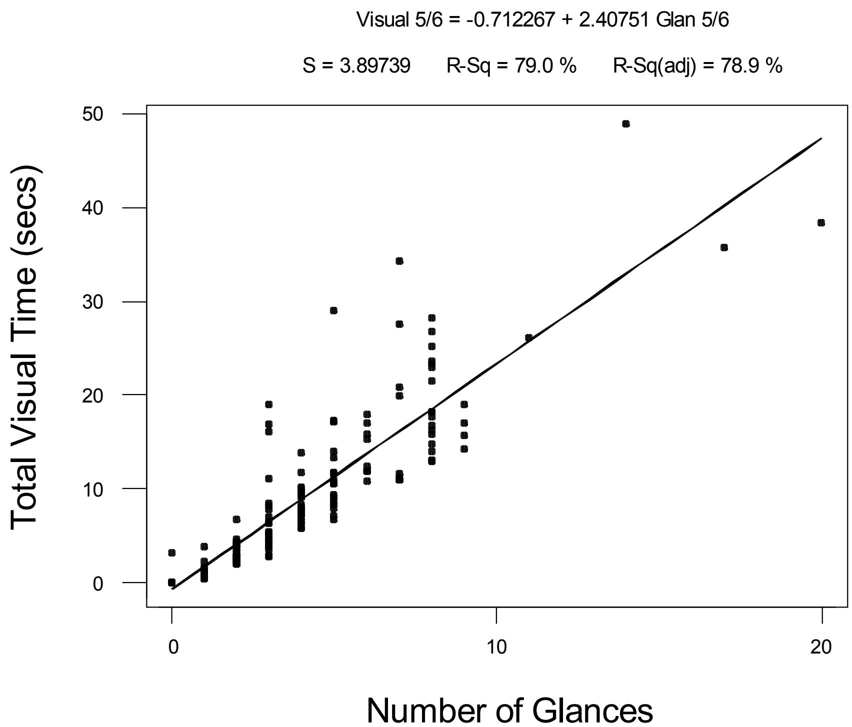

FIGURE 6 Relationship between Number of Glances and Total Visual Time Obtained in the Driving Simulator (Study 1 of Laps 5 and 6)

Measures

	No. of Eye Glances	Total Eye Time	Total Visual Time	Lane Pos. Std. Dev.	Velocity Std. Dev.	Driving Performance Score
	Glan 5/6	Eye 5/6	Visual 5	LSD56	VSD56	DPS
Eye 5/6	0.896 0.000					
Visual 5	0.889 0.000	0.833 0.000				
LSD56	0.004 0.961	0.063 0.405	-0.020 0.794			
VSD56	0.004 0.962	0.062 0.414	0.014 0.859	0.121 0.110		
DPS	0.079 0.295	0.122 0.106	0.095 0.210	0.317 0.000	0.625 0.000	

Key: Cell Contents: Pearson correlation
P-Value

FIGURE 7 Correlation Matrix of Measures Obtained in the Driving Simulator (Study 1)

FIGURE 8 Radio (Radio 3) and Climate Control Unit of the Vehicle Used for Study 2

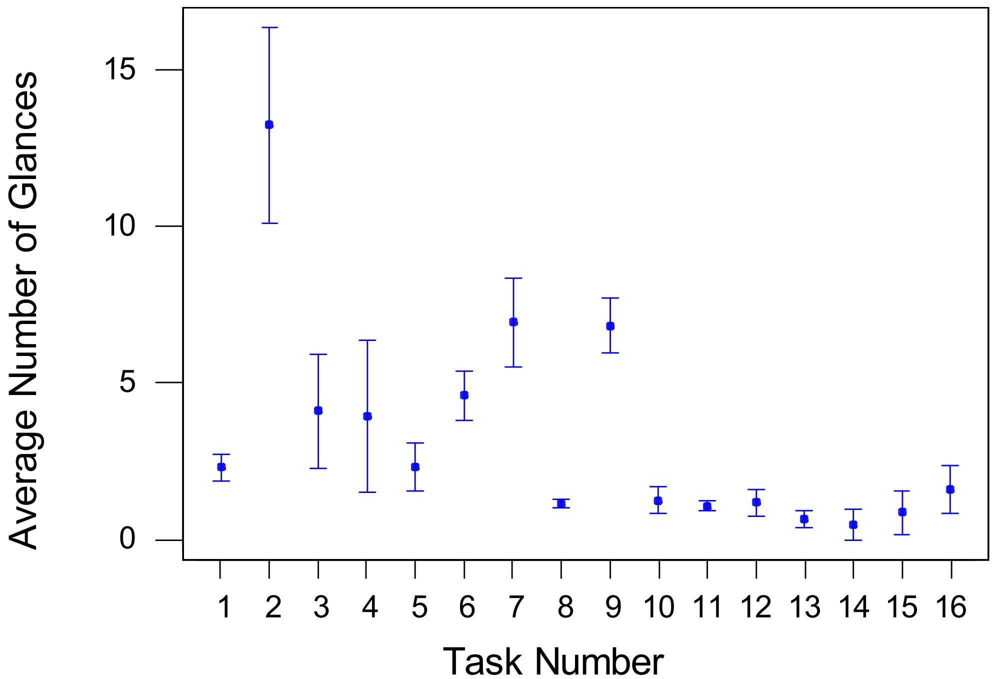

FIGURE 9 Means and 95% Confidence Intervals of Average Number of Glances Made by the Subjects in 16 Tasks during Drive Test

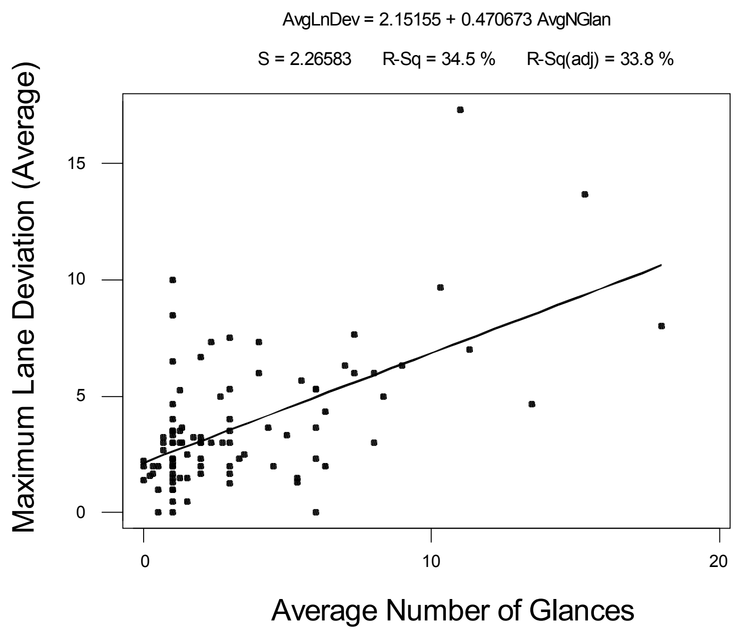

FIGURE 10 Relationship between Average Lane Deviation and Average Number of Glances Obtained in the Drive Test

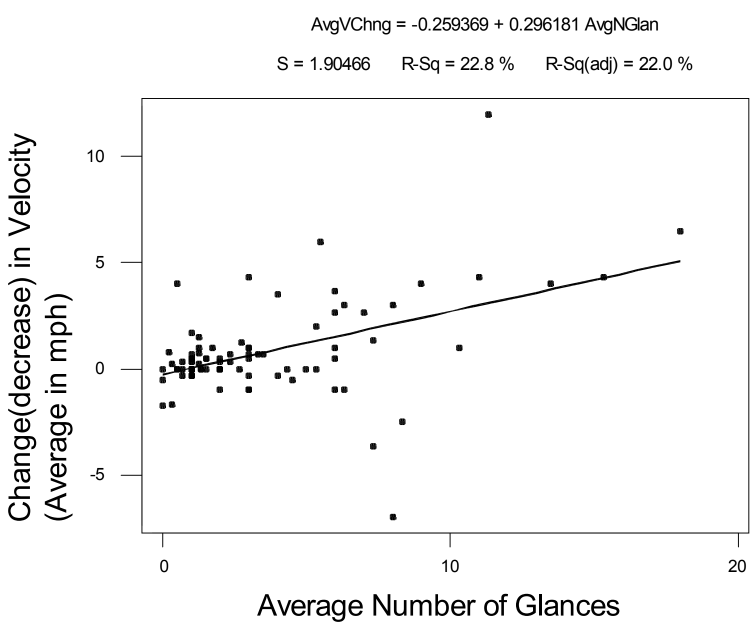

FIGURE 11 Relationship between Average Change in Velocity and Average Number of Glances Obtained in the Drive Test

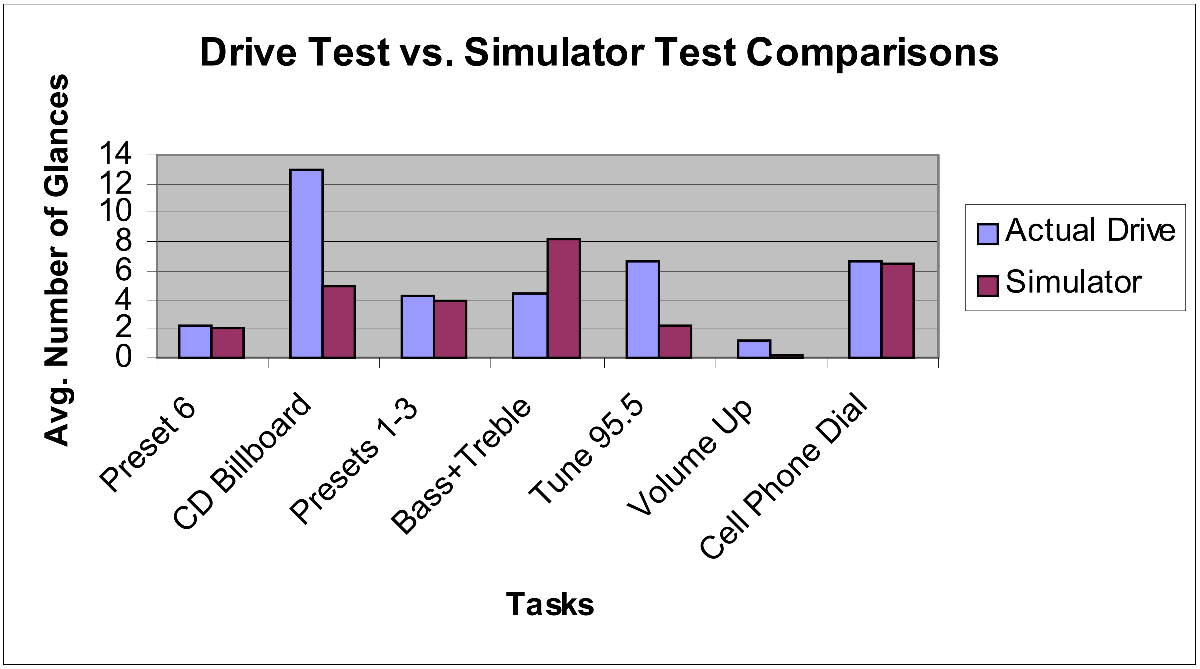

FIGURE 12 Comparison of Average Number of Glances Made in the Drive Test (Radio 3) vs. the Simulator Test (Radio 1)