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Glance analysis of driver eye movements to evaluate distraction

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With the increasing use of in-vehicle devices in cars, an understanding of the safety implications of secondary tasks has become crucial. It is now possible to study the effects of many in-vehicle devices and tasks on driving by using head-mounted eye-tracking devices (HEDs) to collect eye positions and pupil diameters, which have been considered indicators of attentional focus. The collection of eye-position and pupil-diameter data of automobile drivers under on-road conditions and while completing various secondary tasks is described in this paper. Drivers were asked to drive on a preselected two-lane road for a total distance of 22 miles while gaze data were recorded using a HED. Longer off-road fixation durations were observed in radio-tuning and rearview mirror checking tasks, but not in the odometer checking task. In addition, the standard deviations of fixation displacements during a cognitive task involving the computation of a date for a meeting were shorter than those observed during normal driving.

In recent years, there has been an increase in the variety of in-vehicle equipment available to drivers. Cassette players and radios are standard in most cars, and their use is now considered acceptable as a driving distraction. Mobile telephones are now commonplace, and lately navigational and route guidance equipment, real-time information systems, and the like have been introduced into the "driver space." Thus, the proliferation of wireless connectivity and portable computing power has resulted in a flood of in-car devices, each with its own demands on the driver's attention (Cain & Burris, 1999; McKnight & McKnight, 1991). Although most drivers are risk averse, they may not be fully aware of the risks involved when making decisions to use an in-vehicle device.

Because of the increasing presence of in-vehicle information systems in modern vehicles, questions are now being raised about the impact of these systems on driver safety. Manual, visual, and auditory interactions are required with various in-vehicle devices such as radios, compact disk players, cell phones, laptop and hand-held computers, collision avoidance systems, global positioning navigation systems, speech-based e-mail, and other modern information equipment. These devices provide obvious benefits to the driver. However, the increase in risk associated with any corresponding changes in driver workload and monitoring efficiency is not so clear. To improve vehicular safety, some method for the assessment of these distractions is required (Ranney, Mazzae, Garrott, & Goodman, 2000; Serafin, Wen, Paelke, & Green, 1993). However, the parameters that describe the range and frequency of eye movements, which might help evaluate distractions, are not yet fully understood (Hankey, Dingus, Hanowski, Wierwille, Monk, & Moyer, 2000; Lee, Caven, Haake, & Brown, 2000). A recent study by Wierwille and Tijerina (1998), on developing formal definitions of the level of attention required in operating in-vehicle devices, found that "the amount and frequency of visual attention to in-vehicle devices is directly safety relevant" (p. 242). Another simulation-based study of in-vehicle visual, auditory, and manual communication methods concludes that the mode of communication with in-vehicle devices affects the levels of encroachment on the driver's attention (Vollrath & Totzke, 2000).

BACKGROUND

It has long been recognized that an overload of information can cause problems during driving (Matthews & Sparkes, 1996). Brown, Tickner, and Simmonds (1969) demonstrated that concurrent performance of an auditory task impairs judgment of whether a car can be driven through a narrow gap. Harms (1991) showed that mental arithmetic performance is sensitive to the demands of the driving task. A number of investigations have been directed at evaluating the effects of in-car devices on driving performance. Cognitive load problems

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have been related to the use of mobile phones in various ways: Actions such as phone conversations, holding the phone, and dialing while driving (Cain & Burris, 1999; McKnight & McKnight, 1991) have an impact on the driver's attention in different ways. McKnight and McKnight showed that an intense business conversation is different from a social conversation in terms of the cognitive load placed on the driver while he or she is operating a vehicle. The cognitive load in that study was measured by observation of participants' physical response to the various situations depicted in video scenes simulating a drive. Using the speed of the vehicle as an indicator of cognitive load, Pachiaudi and Chapon (1994) showed that whereas conversations on hands-free phones impose a smaller cognitive load than do those conducted on hand-held ones, they do not entirely eliminate it. The risk associated with a phone conversation while driving does not end with the call (Redelmeier & Tibshirani, 1997), due to the driver's continuing to be mentally occupied with the conversation for a short while even after it has been completed. The relative risk of driving with a cell phone has been reported as comparable with the hazard associated with driving while intoxicated (Redelmeier & Tibshirani, 1997).

In this paper a method for evaluating the attentional load of different kinds of devices is presented, so as to allow a comparison of different potential device designs. It is assumed that a relationship between eye movements and attention exists. Although eye movements have been monitored for tracking attention in the past (Yarbus, 1967), advances in tracking hardware and software and increases in computing power have now made it possible to monitor eye movements accurately in real time. Eye-movement patterns of test drivers under actual (on-road) driving conditions and when involved in driving and secondary tasks have also been measured, and the results of these analyses are reported here.

In the past, researchers have used eye movements to gain insight into a person's thought processes and intended actions (McKnight & McKnight, 1991). More recently, the focus has shifted to modeling behavior patterns based on eye movements (Salvucci & Anderson, 1998). Methods of analyzing eye movements have focused largely on separating fixations from saccades based on velocities, aggregation of consecutive points with duration minimums, and digital filtering (Salvucci, 1999). Manual data analysis methods can then be used to identify what a driver is fixating on. A recent technique for automating this process involves tracing fixations. Fixation tracing is "the process of mapping observed action protocols to the sequential predictions of a cognitive process model" (Salvucci, 1999, p. 7). Salvucci (2000; Salvucci & Anderson, 1998) presents an extensive review of current methods of tracing eye movements and develops three new techniques based on Markov models. The models, however, are limited in their application for studying in-vehicle devices because of the underlying assumption that "the task environment in which eye-movement data are collected is (at least for the most part) static" (Salvucci, 1999, p. 10). In the context of the automobile, the scenery outside the vehicle is constantly moving. The driver is continuously tracking other vehicles, signs, and objects outside the vehicle using smooth movements. To quantify how an in-vehicle device impacts safety, an understanding of driving behavior in the absence of that particular distraction must first be developed. Individual differences, the type of roadway, lighting conditions, traffic intensity, and many other factors are expected to play significant roles in these behavior differences. However, these cannot be excluded from real driving conditions. Because at present there are no universally accepted methods for quickly analyzing the large sets of eye movement-data that are generated when these comparisons are made, in this paper a procedure and some results toward this end are presented.

Drivers can focus on only a single stimulus and effectively search up to three targets per second (Moray, 1990). When secondary tasks require visual resources such as fixations, a decrease in the amount of visual resources (as is indicated by fixation durations) allocated to the driving task may occur (Rumar, 1988). Under these circumstances, drivers use multitasking or time sharing. In time sharing, individual visual tasks are completed by sequences of saccadic movements and fixations. As enough information is visually acquired from one stimulus, a saccadic movement is executed, and another stimulus is aligned with the foveal region. This sequence is repeated until one of the tasks is completed (Wierwille, 1993). In driving, the primary stimulus is in the forward view of the automobile, with a range of secondary stimuli competing for the spare visual capacity (Rockwell, 1988). A problem may occur when a driver chooses to monitor too many secondary stimuli instead of the primary task, resulting in a lack of attention to the primary task.

To minimize the increase in risk associated with the execution of secondary tasks, drivers use a safety mechanism limiting the amount of time during which focus is directed off the road to a maximum of approximately 1.6 sec (Wierwille, 1993). However, it is easy to envision situations in which the time required by in-vehicle devices may cause attention to be located away from the road for longer periods. The need for frequent scanning increases with the complexity of the driving conditions—When experienced drivers are presented with complex scenes (i.e., scenes with many details), the frequency of eye movements increases, with decreased fixation length (Chapman & Underwood, 1998). Thus, if in-vehicle devices force attention away from the road, and complex scenes require more frequent scanning, the joint effect of both can be potentially harmful.

To develop a better understanding of driver behavior patterns, an on-road driving study was conducted using a commercial eye tracker to determine where a participant's attention is focused. To understand the effects that distractions have on drivers, the participants were instructed to complete a variety of tasks while driving.

METHOD

Participants

Twenty-eight adults volunteered for this study. Three were rejected because it was difficult to obtain a precise calibration of their eye movements. The participants (9 women and 16 men) were all over 20 years of age and had been driving for at least 1 year on a current driving license. Nine wore eyeglasses, and all were familiar with the area where the test drive was to be conducted.

Materials

A CD containing instructions for nine tasks was prepared. The first track of the CD contained general instructions pertaining to the route to be driven and the procedure to be followed during the drive. Each of the remaining tracks of the CD corresponded to instructions for a specific task. The following is a list of tasks given to all the drivers, whose eye movements were tracked:

1. Turn on the radio and change the station to 1610 AM.
2. Note the prices of gasoline at approaching gas stations.
3. Answer a phone call with a hand-held phone and complete a computational task.
4. Look in the rearview mirror and describe the vehicle that is following.
5. Answer a hands-free phone and complete a memory task.
6. Startle sound of a cellular phone (three rings).
7. Read the odometer.

The head-mounted eye tracker was made by Sensomotic Corporation and was a head-mounted, dark-eye tracker sampling at 50 Hz. The test route involved driving over a total distance of 22 miles, primarily on a semirural, two-lane road. Traffic speeds varied between 25 miles per hour and 45 miles per hour. The drivers used their own vehicles. The eye-position data and the scene video were captured directly on the computer's memory and transferred to a CD for storage.

Procedure

Each driver was asked to first fill out a questionnaire and a consent form. The route to be driven and a general description of the tasks they would be required to perform during the drive were explained to the participants in the laboratory. They then sat in their vehicles in a normal driving posture, and the eye tracker was placed on their heads. After initial adjustments, a sequence of points was presented in front of the vehicle, at a distance of approximately 10 ft. Each participant was asked to look at each of the points, and the corresponding eye position was recorded for calibration purposes. Once the calibration was completed, the driver was asked to drive the test route. Two investigators accompanied the driver: one to play back the instructions on the CD at specific preselected points of the drive, and the second to monitor the ambient lighting conditions and to vary the image threshold during the drive to maintain the best possible image. At the start, the driver was given the instructions on the first track of the CD. This again explained the purpose of the experiment and the route to be followed, as well as a protocol for safe driving. Tests were conducted at different times of the day and under different lighting conditions, such as bright sunlight, cloudy/overcast sky, and so forth. The specific conditions for each drive were not recorded, because a wide range of conditions could be encountered during any given drive.

The computational task required the driver to calculate the day of the week a fixed number of days ahead of a specific calendar date, as when arranging a business meeting. The memory task involved memorization of a list of seven items, to be recalled at the end of the drive. During each of these cognitive tasks, the driver did not have to interact with any device and was not constrained from monitoring the road freely.

Tasks 2 and 6 were repeated twice during the drive. The order in which the tasks were presented was 1, 2, 3, 4, 2, 5, 6, 7, and 6.

RESULTS

Only those portions of data from the driving records for which the data rejection rate was less than 10% were retained. Of the 25 drivers, good data for the entire driving test could be obtained for only 5. This does not mean that all the remaining data had to be discarded; portions of good data were collected from almost every drive. However, the analysis reported here is based on the data of 5 participants only.

Distractions were classified into several different categories. Glance distractions require the subject to divert attention from the roadway for brief (single or multiple glances) periods and perform some secondary task during this interval. These distractions can be further categorized into those that are required for safe vehicle operation (e.g., glances to the rearview mirror or dashboard, as are illustrated in Figures 1 and 2) and glances for in-vehicle device operation (e.g., a glance to the radio, as is illustrated in Figure 3). Glance distractions are easy to identify from the eye-movement data. Multiple glance distractions are distractions that require sustained attention by the subject. However, in order to perform the secondary task (or distraction) and drive simultaneously, the driver multiplexes his/her attention between the two tasks. This can be clearly seen in Figure 3, in which the gaze-position data show that the driver alternates between looking at the road and at the radio until the task is completed. These types of distractions are not as easily identifiable from eye-movement data alone. Cognitive distractions are an additional category of distractions that alter eye movements noticeably. An example of the eye-movement pattern while a subject is engaged in a date calculation task is illustrated in Figure 4.

For the single-glance tasks, the pattern of eye movements immediately prior to the driver's receiving the task can be regarded as the control. This classification is justifiable, because, at any particular point in time, the subject has no indication that the instructions for a task, and the task itself, are imminent. Thus, the period before the task is presented can be considered independent of the task. An advantage of using the period immediately prior to the task as the control is that the environmental conditions for the controls may be similar to the conditions in which the task itself was performed. In Figures 1, 2, and 3, it is clear that the scanning movements that occur before the instruction periods are greatly damped during the task period itself. This lends some support to the premise that the distracting activity influences the primary task (driving).

For multiple-glance tasks and tasks performed under cognitive loading, identification is more difficult. The instruction period, task completion period, and an individual eye movement to the road are illustrated in Figure 3

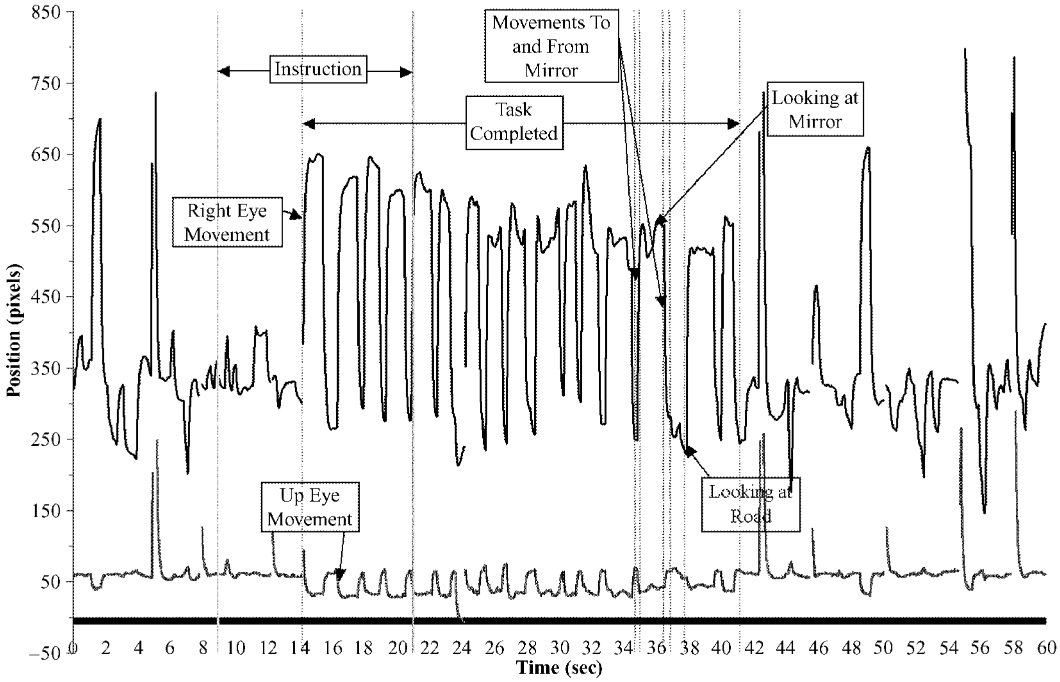

Figure 1. A driver's eye movements plotted against time during the rearview mirror task.

for a subject completing the radio task. The eye-movement patterns in the figure support the theory that, when involved in tasks requiring sustained duration, the driver multiplexes between the primary and secondary tasks. Thus, for the task that required changing the radio station to 1610 AM, the eye movements alternated focal attention between the roadway and the radio until the task was completed. The eye movement toward the radio, and the

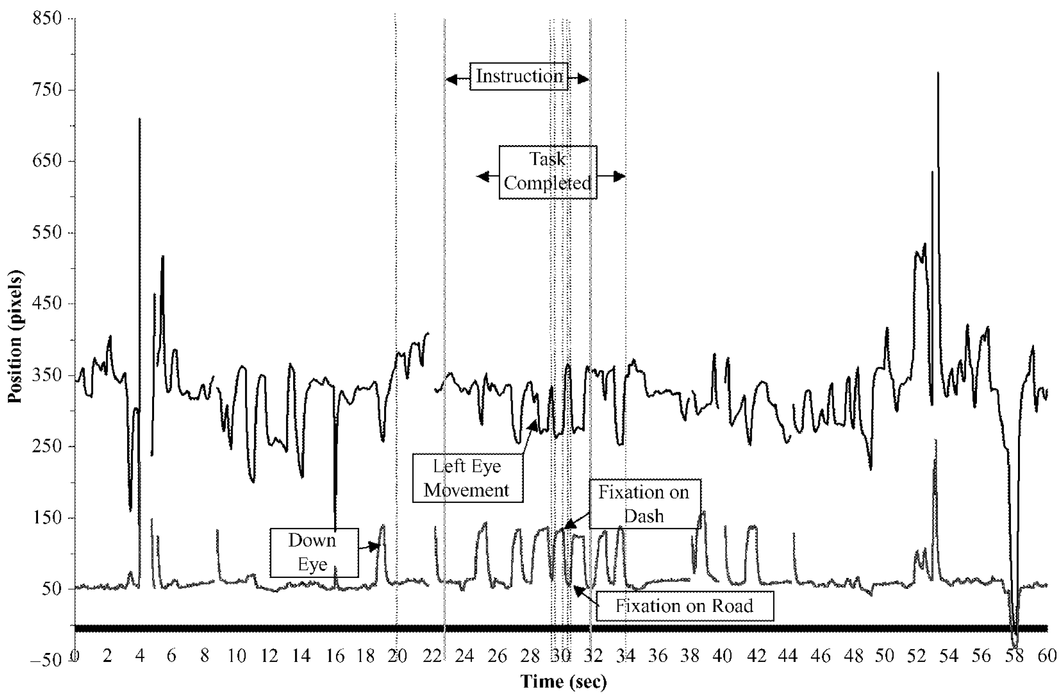

Figure 2. A driver's eye movements plotted against time during the odometer task.

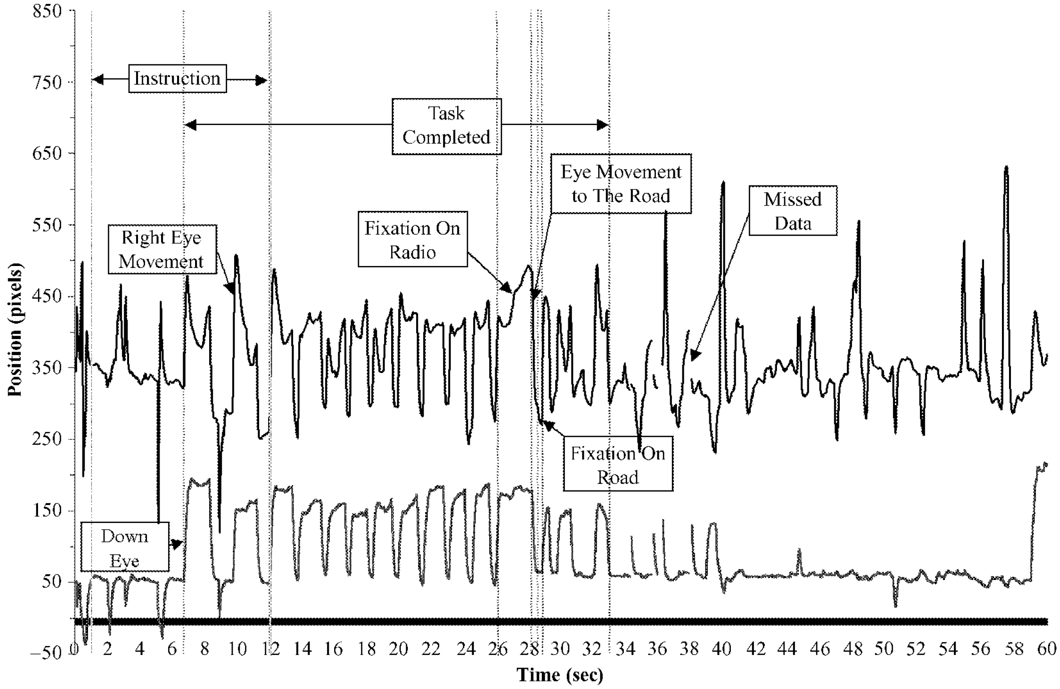

Figure 3. A driver's eye movements plotted against time during the radio task.

fixation on the radio that follows, is preceded by a movement back to the forward view up and to the left of the radio (i.e., the horizontal and vertical positions decrease). The process is repeated until the task is completed. The eye-movement patterns for the rearview mirror task (Figure 1) are similar to those in the radio task. The eye movements for the odometer reading, which is mostly a single-glance task (Figure 2), show up as a one-dimensional

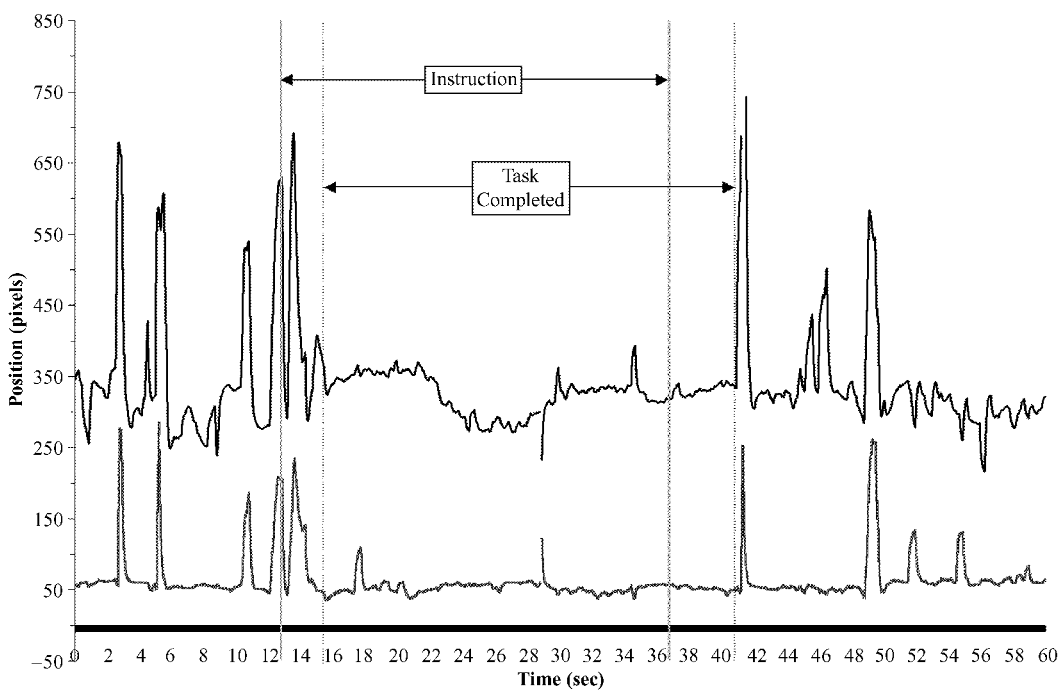

Figure 4. A driver's eye movements plotted against time during the cognitive hand-held phone conversation task.

Table 1
Summary of Glances for 5 Participants Changing the Radio Station

Measure	Participant 1	2	3	4	5	Average
Total task time	21.76	23.92	17.6	24.6	19.38	21.15
Total time off road	12.54	9.06	7.2	8.86	6.86	8.90
Maximum off-road glance	2.02	1.52	1.8	1.5	0.96	1.56
Total number of off-road glances	12	11	10	12	14	11.8
Average length off-road glances	1.05	0.82	0.72	0.74	0.49	0.76
Average movement time	0.26	0.42	0.30	0.38	0.36	0.34
Average on-road glance	0.26	0.56	0.50	0.61	0.19	0.42

Note—All values except those for “Total number of off-road glances” are in seconds.

(vertical) movement to the dashboard. When a driver’s eyes are not focused on the roadway, unexpected stimuli may be missed, requiring another eye movement and fixation before an awareness of changes in the situation can occur. When engaged in the cycle of glances between the device and the roadway, the driver also loses some ability to monitor situations that might be occurring around the vehicle periphery but not directly in front of it.

The reduction in eye movements is even more pronounced during the cognitive phone task, in which the driver’s eyes “wander” around the center of the forward view. This lack of movement possibly corresponds to visual tunneling—a reduction in the useful field of view observed during periods of increased information processing (Williams, 1988). In this situation, it is again likely that the driver may miss stimuli or sudden changes occurring around the vehicle. The recordings confirmed that the reduction in eye movements did not end with the phone call, which ended at the end of the instruction period. This correlates with the findings of Redelmeier and Tibshirani (1997), in which a sustained risk after the end of a cell phone conversation is attributed to afterthoughts related to the conversation.

A glance is defined as the period when a driver is likely to be interpreting information from either the roadway or some in-car device. In the eye-movement data, a glance is identifiable as a steep change in the horizontal or vertical (or both) pupil-location coordinates, followed by a fixation of at least 60 msec. A detailed analysis of drivers’ glances has been completed for the radio, rearview mirror, and odometer tasks. The influence of peripheral vision cannot be estimated using eye-tracking data alone. In each of the glance-type distractions illustrated in Figures 1, 2, and 3, a fixation on the roadway and on the distraction as well as the movements that occur between these fixations have been manually identified. The method of identification included a comparison of the point-to-point velocities, movement directions, and recorded scene data. A summary of the glance patterns for 5 participants performing the radio task is shown in Table 1, whereas Tables 2 and 3 show the statistics for the rearview mirror and odometer tasks, respectively. It is important to note that the glance data tables do not represent the same 5 participants for all tasks. This is because the captured raw data was extremely noisy, and thus different participants were required to develop the five samples used in these statistics. The variability between participants is assumed not to have any bearing on the overall outcome of the summary.

The duration of fixations off the road is mostly less than 1.6 sec, as has been discussed in Wierwille (1993). Only 2 of 113 off-road glances during the radio task and 2 of 95 off-road glances during the rearview mirror tasks exceeded this 1.6-sec threshold, with the largest off-road glance recorded at 2.02 sec. It is worth noting that the extended glances in the radio task were recorded within the last 2 off-road glances (i.e., at the end of the task), and 1 of the 2 glances in the rearview mirror task was the first glance. It is perhaps also noteworthy that all of the long-duration glances are more than double the average glance time, and that the average glance time for the radio task—0.83 sec—is just under half the 1.6-sec

Table 2
Summary of Glances for 5 Participants Looking at the Rearview Mirror

Measure	Participant 1	2	3	4	5	Average
Total task time	26.78	24.28	21.12	17.38	11.04	20.12
Total time off road	14.47	7.60	10.64	9.38	5.02	9.42
Maximum off-road glance	1.46	1.98	1.5	2.0	1.24	1.63
Total number of off-road glances	16	10	10	7	7	10
Average length off-road glances	0.90	0.76	1.06	1.34	0.72	0.96
Average movement time	0.26	0.39	0.32	0.31	0.32	0.32
Average on-road glance	0.25	0.98	0.46	0.60	0.3	0.52

Note—All values except those for “Total number of off-road glances” are in seconds.

Table 3
Summary of Glances for 5 Participants Looking at the Odometer

Measure	Participant 1	2	3	4	5	Average
Total task time	9.34	6.46	7.24	15.42	8.02	9.23
Total time off road	2.68	2.5	4.66	5.92	1.82	3.52
Maximum off-road glance	0.58	1.3	1.32	1.1	0.58	0.98
Total number of off-road glances	7	3	4	10	4	5.6
Average length off-road glances	0.38	0.83	1.12	0.59	0.46	0.69
Average movement time	0.30	0.47	0.23	0.24	0.39	0.33
Average on-road glance	0.42	0.56	0.24	0.52	1.03	0.55

Note—All values except those for "Total number of off-road glances" are in seconds.

bound, whereas the average rearview mirror glance—0.96 sec—is a little longer, and the average dashboard glance is 0.69 sec.

Figures 5 and 6 illustrate the difference in glance lengths to and from the roadway for the single- and multiple-glance-oriented tasks. Tables 1 and 3 summarize these data. In Table 1, the average on-road glance time ($\mu_{r,r}$) for the radio task (0.42 sec) is shorter than the average off-road glance time ($\mu_{r,o}$) during the same task [0.76 sec; $t(4) = 3.94$, $p = .027$].

The rearview mirror task, summarized in Table 2, has also been similarly analyzed. The average off-road glance time ($\mu_{rv,o}$) during the rearview mirror change task (0.96 sec) differs significantly from the average on-road glance for the rearview mirror task [$\mu_{rv,r} = 0.52$ sec, $t(4) = 2.54$, $p = .032$]. For the odometer check task, the average off-road glance time ($\mu_{s,o} = 0.69$ sec) is not significantly different from the on-road average glance time [$\mu_{s,r} = 0.55$ sec, $t(4) = 0.52$, $p = .32$] (see Table 3).

Tasks involving cognitive distraction can be analyzed for the statistics of the scan patterns that occur while the driver executes the task. A typical trajectory of the eye-movement data is shown in Figure 4. Table 4 summarizes the data for the date computation task, and Table 5 presents the data for the memory task. Table 6 shows the data used as the control data. The control considered

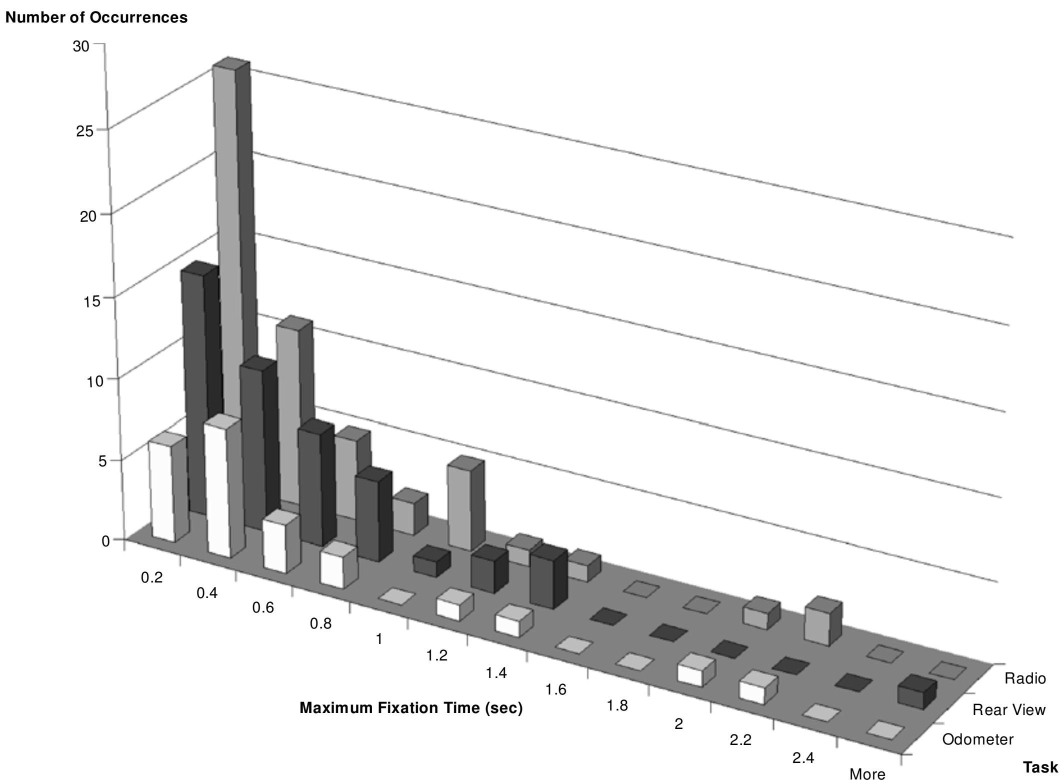

Figure 5. On-road glance duration distribution for glance tasks.

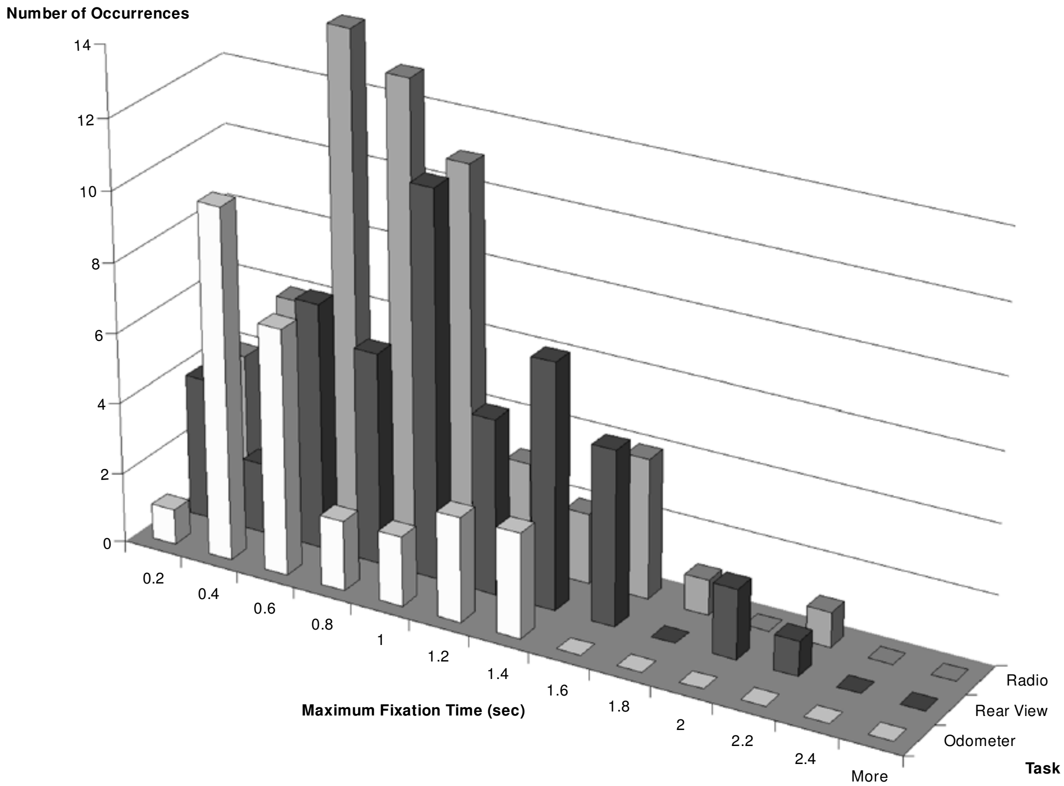

Figure 6. Off-road glance duration distribution for glance tasks.

here was computed from the entire data record without the instruction and task intervals. A comparison is then made against the mean and standard deviation of eye-movement displacements computed from this control.

To identify differences in the eye-position movement patterns of the participants during the cognitive tasks and the control data, the standard deviations of the eye-movement displacements during the task durations were compared. Although it is possible to compare the mean horizontal and vertical positions as well, it is not meaningful to do so, since these positions are recorded relative to the scene data frame, and the location of the eye gaze is not precisely computable. Instead, the standard deviations of the displacements of the horizontal and vertical movements during the tasks have been compared with the standard deviations of the control using an F test. For the vertical movements, $F(4,4) = 11.11$, $p < .05$, and F critical$(4,4) = 6.39$. For the horizontal eye-movement data, $F(4,4) = 8.20$ and $p < .05$. Thus, the data collected present evidence that the standard deviations of the eye-movement durations under cognitive load (date calculation task) is less than the standard deviation of eye-movement durations under normal conditions.

A similar analysis is done for the second cognitive task. As in the case of the first cognitive task, the standard deviations of both the horizontal and vertical displacements are compared with the control. For the horizontal and vertical eye-movement data, $F(4,4) = 4.35$ and 4.76, respectively. In this case, the results are not conclusive, and further data collection is required.

DISCUSSION

In this paper a procedure for collecting driver eye movements under on-road conditions using a head-mounted eye tracker is detailed. The data has been ana-

Table 4
Eye-Movement Summary for the Date Computation Task (in Seconds)

Measure	Participant 1	2	3	4	5	Average
Total task time	25.28	21.46	19.32	32.88	32.6	26.31
Average horizontal position	325.96	331.00	256.42	236.41	297.30	289.42
Average vertical position	52.56	108.64	87.54	80.09	104.31	86.63
Standard deviation horizontal positions	26.32	29.12	35.39	70.79	39.51	40.23
Standard deviation vertical positions	8.59	8.52	16.04	26.03	11.65	14.17

Table 5
Eye-Movement Summary for the Memory Task (in Seconds)

Measure	Participant 1	2	3	4	5	Average
Total task time	49.66	53.24	56.88	52.1	51.26	52.63
Average horizontal position	317.19	317.51	264.59	230.24	304.60	286.83
Average vertical position	58.81	114.06	87.98	83.37	111.57	91.16
Standard deviation horizontal positions	37.70	47.81	50.20	68.28	43.75	49.55
Standard deviation vertical positions	10.04	15.52	10.30	20.71	21.55	15.63

lyzed to compare a driver's performance on a variety of in-vehicle tasks. The statistics computed for the data collected in this study are consistent with statistics noted in earlier studies. Three types of eye-movement patterns in response to secondary tasks, including distractions (i.e., tasks that take the eyes off the road, but are necessary for driving) have been identified: (1) single-glance tasks that include eye movements for checking the rearview mirror and odometer; (2) multiple-glance tasks, such as radio station change tasks, which exhibit a time-sharing pattern; and (3) tasks under cognitive load, in which the eye-movement extent variance is reduced. Time-sharing tasks result in a division of attention between the primary task of driving and the instructed secondary task. The 1.6-sec upper bound on the natural off-road glance time of Wierwille (1993) is also observed, since only 4 glances of 208 are noted as exceeding the earlier reported bound of 1.6 sec. In the present study, the safety implications of the off-road tasks are not explicitly considered. Also, further analysis of the data and additional testing is required to ascertain any causes underlying the longer glance lengths; it is possible that these take place when road conditions are favorable or that these long glance durations take place when the task conclusion is imminent. However, further data collection is required before any definitive statements can be made.

Glance analyses were performed for the single- and multiple-glance tasks. The radio and rearview mirror tasks show that there is a difference in the off-road and on-road glance times. This difference is not significant for the odometer task. The reason for the difference may be that both the radio and the rearview mirror tasks require the collection of significantly more data than does the odometer task, once the device is brought into focus. However, in the case of the odometer task, the instructions required the driver to read the counter, which typically involved one or two glances in most cases. The angular distance for the odometer task was also the least of all three glance tasks.

The lack of a significant difference in the on-road glance times for all three tasks confirms that the time required to acquire visual information from the road is not task dependent within this experiment, whereas the actual off-road glance times are task specific. It is possible that some interaction between glance-type tasks and cognitive tasks is confounded in the results; however, this could not be resolved, nor was any attempt made to do so in this experiment.

The analysis of the two cognitive tasks is more interesting. The conversation equivalent to the hand-held cell phone requiring date calculation and that equivalent to the hands-free phone requiring a memory task showed at least marginally significant differences in the standard deviation of eye-movement extent from the control data. For the date calculation task, the differences are significant at $\alpha = .05$. The implication of this difference is that, when engaged in a computationally intense task, drivers do not scan the road as much as they do otherwise. This is also indicated for the memorization task. The safety implications of this finding are not investigated explicitly here—the consequences will require investigation of the amount of reduction in information as well as in response time. Numerous additional factors, such as road conditions, driver capabilities, lighting conditions, traffic intensity, and the like, are also likely to influence the difference and must also be included in any future investigation. However, for the cognitive task, in which the eye-movement standard deviation is significantly smaller than under normal driving conditions, it can be asserted that the effect on safety, if any, can only be detrimental: If drivers overscan under normal conditions, then the factor of safety is reduced. If they do not overscan under normal conditions, then the reduction is conceivably hazardous.

Table 6
Summary of Control for the Entire Drive Excluding Task Completion (in Seconds)

Measure	Participant 1	2	3	4	5	Average
Average horizontal position	334.82	339.23	292.01	234.65	315.31	303.21
Average vertical position	64.56	111.89	96.46	80.13	107.71	92.15
Standard deviation horizontal positions	89.20	82.18	89.96	97.92	88.72	89.59
Standard deviation vertical positions	28.56	22.43	28.43	27.93	26.54	26.77

The methods reported in this paper are potentially useful for detecting and classifying the level of interaction (i.e., level of distraction) required in performing cognitive and manual secondary tasks. Glance analysis and variance analysis of drivers' eye-movement patterns may be useful tools in the detection and classification of driver distraction. Glance analysis can be used to compute metrics for the time taken to complete various in-vehicle tasks, whereas the study of the variance of recorded eye positions quantifies the reduction in eye movements that occurs as a driver is engaged in cognitive thought. Future work will continue this examination of glance data by studying the level of attention devoted to tasks such as manual and hands-free cell phone operation, under controlled road situations.

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