

On-Road Driver Eye Movement Tracking Using Head-Mounted Devices

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Abstract

It is now evident from anecdotal evidence and preliminary research that distractions can hinder the task of operating a vehicle, and consequently reduce driver safety. However with increasing wireless connectivity and the portability of office devices, the vehicle of the future is visualized as an extension of the static work place - i.e. an office-on-the-move, with a phone, a fax machine and a computer all within the reach of the vehicle operator. For this research a Head mounted Eye-tracking Device (HED), is used for tracking the eye movements of a driver navigating a test route in an automobile while completing various driving tasks. Issues arising from data collection of eye movements during the completion of various driving tasks as well as the analysis of this data are discussed. Methods for collecting video and scan-path data, as well as difficulties and limitations are also reported.

Keywords: Perceptual reasoning, Ergonomics, Camera calibration, Tracking

1 Introduction

Because of the increasing presence of In-Vehicle Information Systems (IVIS) in modern vehicles, questions are now being raised about the impact of these systems upon vehicle safety. Manual, visual, and auditory methods are being used to interact with various in-vehicle devices such as radios, compact disk players, cell phones, laptop, palmtop computers, collision avoidance, global positioning navigation systems, speech based e-mail and other modern information equipment. These devices provide obvious benefits to the driver - however costs associated with changes in driver workload and monitoring efficiency are not so clear. While there is little argument that visual, auditory, biomechanical, and cognitive distractions result from the use of these devices, the safety implications are difficult to quantify. To improve vehicular safety, some method for the assessment of these distractions is required ([Ranney et al. 2000] and [Serafin et al. 1993]). However, the exact parameters with which a minimum threshold can be defined are not yet fully understood

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([Lee et al. 2000] and [Hankey et al. 2000]). A recent study [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". Another study ([Vollrath and Totzke 2000]) on in-vehicle communication methods concludes the mode of communication with in-vehicle devices does result in differences in levels of encroachment on the driver's attention. Car radios have been largely accepted as an acceptable driving distraction while other in-vehicle information systems have not been so readily accepted ([McKnight and Mcknight 1991] and [Cain and Burris 1999]). Fundamentally, a distraction is anything that takes attention away from the primary task. In the case of a driver, this is anything that takes the driver's attention away from the driving task. In the absence of knowledge about the levels of distraction that result from secondary tasks, it is difficult to predict what the effect of multiple tasks is on the primary (driving) task. While most drivers are risk adverse, they are not fully aware of the involved risks when making decisions to use an in-vehicle device. Many researchers have addressed problems relating to driver distractions and a comprehensive review of the literature and studies on various in-vehicle devices, completed in [Reimer and Sodhi 2002], is summarized below.

1.1 Existing Research Into The Distraction Problem

It has long been recognized that an overload of information processing capacity causes problems with driving performance [Matthews and Sparkes 1996]. Existing research provides a number of examples of overload. In [Brown et al. 1969] it is demonstrated that concurrent performance of an auditory task impairs judgments of whether the car can be driven through a narrow gap. In [Harms 1991] mental arithmetic performance is shown to be sensitive to the demands of the driving task. 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. Mobile telephones are now widespread, and lately navigational and route guidance equipment, real-time information systems etc. have been introduced into the "driver space". A number of investigations have been directed at evaluating the effects of such equipment on driving performance. Cognitive load problems have been related to the use of mobile phones in various ways - actions such as phone conversations, holding the phone, and dialing while driving ([McKnight and Mcknight 1991] and [Cain and Burris 1999]) have an impact upon the driver's attention in different ways. In [McKnight and Mcknight 1991] an intense business conversation is shown to differ from a social conversation in the cognitive load placed on the driver while operating a vehicle. It appears that hands free conversations do result in reduced cognitive loads, nevertheless there is an increase in the load compared with normal driving ([Pachiaudi and

Chapon 1994] and [Cain and Burris 1999]). The relative risk of driving with a cell phone has been reported as comparable with the hazard associated with driving while intoxicated ([1997]) and it is stated that "the relative risk is similar to the hazard associated with driving with a blood alcohol level at the legal limit". It has also been shown that the risk associated with a phone conversation while driving does not end with the call ([Redelmeier and Tibshirani 1997]), and it is conjectured that the sustained risk is due to the driver being mentally occupied with the past conversation after it is actually over.

This paper focuses on the use of eye tracking methods to monitor how various distracters affect a driver, assuming a relationship between eye movements and attention. While this mode of tracking attention has been used in the past, recent advances in tracking hardware and software, as well as increases in computing power have now made attempts at monitoring driver attention vis-a-vis eye movement tracking feasible for real time analysis. Even so, there are several issues that must be addressed when using eye movement tracking, and some of these are detailed in this paper.

1.2 Eye Movements and Attention

The human oculomotor system is controlled directly from a section of the brain stem through three pairs of extraocular muscles, each responsible for one of the three directions of eye movement; horizontal, vertical, and torsional. The most basic movement, for which no selective function exists, is called physiological nystagmus which is caused involuntarily by tremors in the extraocular muscles, resulting in slight shifts of the ocular image in relation to the retina. All the remaining eye movements have one thing in common - they have some function in controlling where the eyes fixate. A Saccadic eye movement is the fundamental search movement for the eye. It can be best described as a ballistic motion to propel the eye to a new object of interest. Saccades are further described as pre programmed movements, and once initiated, their path or destination cannot be voluntarily altered. A certain amount of time, between 150 and 200 ms can be attributed to planning and executing a saccade, while the actual movement only takes a maximum of 30 ms while reaching a maximum speed of up to 900 deg per sec. The time between saccades is when the eye processes visual information by fixating on a target.

When the object of interest is in motion, a third type of eye movement known as a smooth pursuit movement is used as opposed to a sequence of saccades and fixations. The purpose of a smooth pursuit movement is to track a moving object and keep it in foveal view once a saccade places the object in focus. This movement allows for visual information to be extracted from a moving target. It functions using a feedback process that constantly uses information related to the speed of the moving object to predict where to move the eyes. In order to keep an object centered in the fovea of both eyes a fourth type of movement known as vergence movements are used in conjunction with smooth movements. Vergence movements are slow, 10 deg per sec, disconjugate movements used to select the distance of the target by aligning the object in the center of both fovea. A disconjugate movement is described as a situation where each eye is looking in different directions. Two final involuntary eye movements are vestibular and optokinetic movements, which work in conjunction to keep an object in view when the head moves. Vestibular movements are triggered by signals from the inner ear to oppose rotational movement,

while optokinetic movements are triggered by optical translations opposing uniform movements in the visual field.

Eye movements in many cases are assumed to be predictors of attention. An eye-tracking systems can therefore be used to collect information about how a driver responds to different situations on or off the road [Recarte and Nunes 2000]. Two different models for eye movements and attention are described in [Henderson 1993]. In the first a sequential attention model describes attention as being "directed to the specific location toward which the eyes will move prior to a saccadic eye movement". In the second model, attention is described as being "allocated to all locations in the general direction of the impending saccade rather than to the specific target location". Similar findings relating eye movements directly to attentional shifts for "ordinary activities" have been found by [Recarte and Nunes 2000]. Saarinen [Saarinen 1993] found that "observers could not shift attention away from fixation to an extra foveal position as efficiently as they could maintain attention at fixation". However there is one difficulty that needs to be remembered. Until some period before the saccadic movement starts, models of eye movement and attention presume that the movement can be canceled [Salvucci 2000]. It is therefore easy to conceive that situations exist where attention is directed on objects but no eye movement is ever executed to bring it into view. In order to simplify the problem of understanding where attention is focused these situations are assumed to be unimportant. While eye movements are not a perfect indication of cognitive process, they are a "good index of the moment to moment on-line processing activities that accompany visual cognitive tasks" [Rayner 1992]. In the past, researchers have used eye movements as an insight to person's thoughts and intended actions [McKnight and McKnight 1991]. More recently, the focus has shifted into modeling behavior patterns based upon eye movements [Salvucci and Anderson 1998]. In either case information about where a subject is looking must be collected at high frequency, to capture any sudden changes in a persons actions.

Eye movements recorded at high frequencies can give important clues to human behavior. A greater understanding of what information people use in problem solving can be determined by how long it takes to process information. Basic work in the field was completed in [Just and Carpenter 1976] where the relationship between the locus, duration, and sequence of eye fixations and the activity of the central processor was investigated. Eye movement data looks at where an individual is collecting visual information over a very small scale currently in the range of 50 to 400 HZ. Higher collection rates are only available in systems where the subjects head is fixed. Commercial head mounted eye trackers can currently collect eye movements in the range of 50 to 240 HZ while a video recording of the forward scene can be made at 30 HZ. Traditional methods of analyzing eye movements have focused largely on separating fixations from saccades based upon velocities, aggregation of consecutive points with duration minimums, and digital filtering [Salvucci 1999]. Manual methods can then be used to identify what a driver is fixating on. A recent technique to automate 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]. Salvucci ([Salvucci and Anderson 1998], [Salvucci 1999]) presents an extensive review of current methods of tracing eye movements, and develops three new techniques based upon Markov models. The models however are limited their application for studying in-vehicle devices because of their assumption that "the task environment in which eye-movement data are collected

is (at least for the most part) static". In the context of the automobile the scenery outside the vehicle is constantly moving. The driver is tracking other vehicle, signs, and objects outside the vehicle with smooth movements. To detect patterns in driver's eye movements new methods of analysis need to be developed.

To develop a new method of analyzing dynamic scenes an understanding of visual search in a dynamic setting is needed. With the addition of smooth eye movements, the analysis of scan paths for dynamic scenes is more difficult than the associated problem in a static scene, since conclusions about eye movements and their relation to the actual scene can only be made at discrete intervals relating to the recording of the scene camera [Stark and Ellis 1981]. The low recording rates of scene cameras make it necessary to rely on eye movements recorded at higher frequencies to understand where the subject is looking. Driving is one of many tasks that occurs in a dynamic setting and therefore exhibits this problem. Drivers, limited by their visual resources, can only focus on a single stimulus and search up to three targets a second effectively [Moray 1990]. Frequently the need arises to concurrently monitor many different visual stimuli such as the speedometer, rear view mirror, a car in front, to the side, or other aspects of the visual scene not related to driving. When visual resources are allocated to secondary tasks a decrease in the amount of visual resources allocated to the driving task has to occur [Rumar 1988]. Time-sharing is used as a method of partially overcoming this limitation. With time-sharing individual visual tasks are completed by sequences of saccadic movements and fixations. After enough information has been acquired from one stimulus, a saccadic movement is executed, aligning another stimuli with the central region of the fovea. The sequence is repeated over again until one of the tasks is complete [Wierwille 1993]. The primary stimulus in many instances is the forward view of the automobile with a range of secondary stimuli competing for the spare visual capacity [Rockwell 1988]. A problem can 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. The driver therefore cannot interpret enough information from the road.

Drivers naturally develop a safety mechanism to counteract this problem, by limiting the amount of time focus is directed off the road for comfort, to a maximum of approximately 1.6 seconds [Wierwille 1993]. Due to this limitation a difficulty exists when information needs to be extracted from highly complex, or unknown secondary tasks, such as the cluttered dashboard of a new car or dialing a cell phone. In this situation the time to search and complete a task may have to be longer than the comfort limit. When information is extracted from complex scene experienced drivers exhibit a larger number of eye movements with decreased fixation length [Chapman and Underwood 1998].

Other problems can be identified in a drivers visual field. The visual field is a region of flexible size and shape that includes both areas of direct focus and indirect focus. The useful area of the visual field or functional field of view has been described as "the area around the fixation point from which information is being briefly stored and read out during a visual task" [Williams 1988]. A relationship between the size of the visual field and workload also exists, when too much information is being processed the useful field of view contracts to prevent overloading of the visual system ([Rantanen and Goldberg 1999], and [Miura 1990]). In addition, a reduction in the mean gaze duration can be found [Miura 1990]. The reduction in visual field size can be related

to two separated phenomena. Tunnel vision, represented by a clear reduction in aperture angle of the visual cone, and a general decrease in peripheral visual performance independent of the visual cone angle [Rantanen and Goldberg 1999]. Drivers affected by these changes rely on a greater number of shorter fixations to detect and acquire information from targets ([Miura 1990] and [Crundall et al. 1998]). Crundall et al. [Crundall et al. 1997] concludes that slower reaction times result. An on the road driving study, using a commercial eye tracker as a method of determining where a subjects attention is focused, was completed to further understand the effects that distractions have on drivers as well as verifying the results of some previous experiments.

2 Tracking Drivers Eye Movements in an On The Road Setting

The purpose of this investigation was to analyze the gaze pattern of drivers when they are being distracted. In the experiment 24 people, who are all in possession of a valid driver's license, were asked to drive a route of about 20 miles with the Head mounted Eye-tracking Device HED on. It was recommended that subjects use the vehicle that they most often drive, so that they would already be familiar with the controls. During the ride the subjects were confronted with several distractions, which were presented by one of the investigators. When driving past a pre-determined position on the route for each distraction, the researcher played back a pre-recorded CD track initiating the specific distraction. The distractions which the subjects were confronted with were:

1. Turning on the radio and changing the station to 1610 AM.
2. Note the prices of gasoline from approaching gas stations.
3. Answering a phone call without a hands free device and completing a computational task.
4. Looking in the rearview mirror and describe the vehicle that is following.
5. Answering a hands free phone call and completing a memory task.
6. Reading the odometer.
7. Startle sound of a cellular phone (3 rings).

2.1 System Setup

To operate the system in a car the following items were required:

1. IView operator PC.
2. Computer monitor for eye level tracking.
3. HED.
4. CD player and speakers.
5. UPS power pack.

The iView operator records and stores all the incoming data from the HED. The monitor is necessary to make real time adjustments to the pupil and corneal reflection threshold. When driving in natural light conditions, the light intensity changes with cloud cover, time of day, tree / bridge cover etc. This affects the contrast of the pupil and corneal reflection. This effect is most pronounced when it is sunny.

Therefore, cloudy days will give better eye data. Two researchers travel with the subject, inside the car. One researcher operates the iView PC and the other researcher controls the distraction presentation. During an experimental run, the distracting researcher is assigned the following tasks:

1. Activating the distractions.
2. Note the traffic circumstances.
3. Asking particular questions.
4. Noting the answers.

2.2 System Calibration

In order to capture the gaze position correctly, the system has to be calibrated for each driver. This is done by defining a number of points where the subject must focus on. The number of points and their positions can be defined with the iView software. The calibration procedure gives the option of being able to define a 2-points, 5-points, 9-points and a 13-points calibration. The more points used, the more accurate is the calibration and thus the gaze position. When encountering difficulties during calibration, a couple of things were tried to facilitate calibration. First, the number of points used for calibration can be decreased. Another option is to decrease the calibration accept level. The higher the acceptance level, the harder it is to accept a gaze position. As a result the gaze position is more accurate. Correspondingly, the lower the acceptance level, the faster the system will accept a gaze position, but the calibration is less accurate. The points are displayed on the computer screen. Dragging and dropping the points manually can change the placement of the calibration points. This is very convenient when a point is placed on a location where the subject can hardly see it or has to turn their eyes in an unnatural position. With this option the point can be shifted to a better location. To solve the problem of calibrating the system with the driver seated in the car, the car was driven in front of a flat surface such as a garage door. This provides a flat uniform wall where the calibration points could be easily located with a laser pointer or stick.

2.3 Data Recording

As mentioned earlier, the HED uses three different cameras: the scene camera, the eye camera and the IR camera. The data coming from the scene camera and the IR camera are stored digitally, as an MPEG file and ASCII file respectively in the PC, while the eye camera data can be stored via a video recorder. The digital data is used for the analysis and the eye camera data is used for adjusting the contrast of the pupil and corneal reflection during the calibration and the drive. For this reason, only the scene camera and IR camera data was recorded for this research.

When the eyes are closed the IR camera is unable to detect the pupil and the corneal reflection. As a result, a number of zeros corresponding to the eye position jumping from the current position to the upper left corner of the scene video will be recorded in the ASCII file. The upper left corner is considered the origin of the coordinate space, with right movements resulting in higher horizontal values and upwards movements resulting in greater vertical values.

When the calibration procedure is successfully completed the subject is ready to drive, the scene camera and IR camera data begin recording. The subject is now asked to look straight forward and close his/her eyes for three seconds.

This is done to synchronize the two camera systems. The synchronization can later be used when trying to identify the scene that relates to measurements recorded in the ASCII file. This procedure proved to be critical in understanding how the recorded scene relates to the recorded ASCII file.

3 Results

To evaluate the effect of in-vehicle tasks on the driver, focus has been placed on analyzing eye movements as recorded in the ASCII file using the recorded scene as a method of determining the physical location of a movement. Since the average length of the drive was 39 minutes, an average of $39 * 60 * 50 = 117,000$ eye positions measurements were made for each subject. Before a detailed analysis could begin, problems associated with environmental conditions that limit the effectiveness of the eye tracker while recording data needed to be addressed. Two limitations of eye tracking were observed when a comparison of the collected data and recorded video was made. First the eye tracking equipment cannot obtain a position measurement when the eye is closed, say when blinking. In this situation the eye tracker assumes the eye's position is at the origin the upper left hand corner. Second, sunlight interferes with the IR recording device, resulting in collected positions outside of the feasible region of measurement. Before any in depth analysis can be completed both types of false data need to be removed from the data stream. The data was filtered to remove both positions recorded at the origin and points outside the feasible region. When the horizontal and vertical eye positions are plotted against time, the filtered sections are missing as illustrated in (Figure 1). A detailed investigation into eye movement patterns could then be completed.

Basic plots of recorded data positions for a particular subject are shown against time for four of the tasks presented to the driver in this study: changing the radio (Figure 1), checking the rear view mirror (Figure 2), reading the odometer (Figure 3), and a hand held cell phone conversation (Figure 4). The figures show the pattern of eye movements before, during, and after a task is given to the driver. Since the subject had no indication when the instructions for a task were to begin, eye movements patterns before the start of instructions in any figure can be considered controls. However it is difficult to classify any movements recorded as being representative of "normal driving", as will be discussed later. Two basic patterns can be identified from the results, one in which glances are made between the roadway and the device (radio, rear view mirror, and odometer) (Figures 1, 2, and 3) and another where the driver is in a state of static fixation on the center of the road (Figure 4). Each of these situations needs to be analyzed in a different manner, with relation to the effects on driving performance.

In the radio task it is easy to see how the drivers eye movements follow the task sharing model. The instruction period, the period where the task is completed, and an individual eye movement off the road are illustrated in (Figure 1). When the driver's eyes move to the radio, which is located down and to the right of the forward view, the horizontal position and vertical positions increase, with a delay occurring at the position of the radio where some action is completed until a movement back to the forward view is completed, up and to the left ie. the horizontal and vertical positions decrease. The process is repeated until the task is completed. The rear view mirror task, (Figure 2), is very similar to the radio task, except instead of a downward movement to the radio, an upward movement to the mirror

is combined with a movement to the right. The odometer reading, (Figure 3), shows more of just a one dimensional movement to the dashboard. When the driver's eyes are not focused on the roadway, unexpected stimuli will not be focused close to the fovea, requiring another eye movement and fixation before an understanding of the situation can be made. The driver, when engaged in the cycle of glances between the device and the roadway, also loses the ability to monitor situations that could be occurring around the vehicle peripheral but not directly in front. These types of movements are responsible for many of the spikes found in the control space around the illustrated tasks.

A lack of eye movements to surrounding locations is even more pronounced during the cognitive phone task where the drivers eye "wander" around the center of the forward view. The lack of movement possibly corresponds to visual tunneling a reduction in the useful field of view observed during periods of increased information processing. In this situation it is again unlikely that the driver would notice situations occurring around the vehicle. It was also observed that the reduction in eye movements did not end with the phone call ie. end of the instruction period. Relating to the situation described in [Redelmeier and Tibshirani 1997], where a sustained risk after the end of a cell phone conversation is related to after thoughts. Even with the ability to identify distractions that cause a reduction in eye movements, risk matrices to categorize their safety effects are difficult to compute. The ability to develop these matrixes requires an understanding of a "normal" driver's eye movement pattern. Methods of comparing hypothesized "normal" driver's eye movements are needed to fully understand the when a driver is under the effects of a cognitive task.

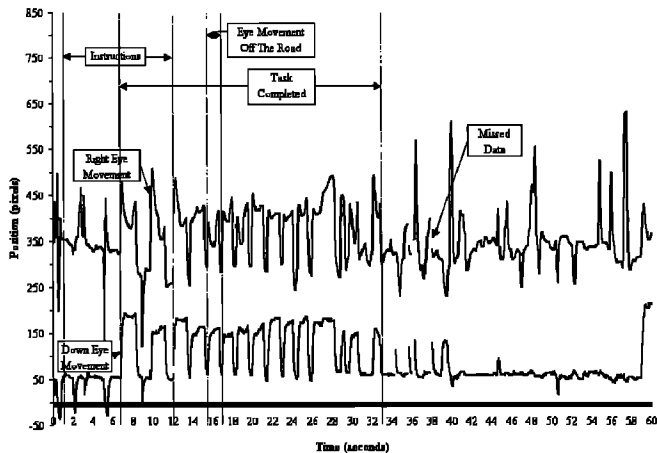


Figure 1: Horizontal (top line) Vertical (bottom line) eye movements plotted against time during the radio task

3.1 Glance Measurements

A detailed analysis of glances has been completed for the radio, rear view mirror, and odometer task. If a glance is defined as the static time when a driver is likely to be interpreting information from either the roadway or some in-car device, some hypothesis can be formulated on how long a driver's eyes are off the road to complete a particular task. To simplify the analysis it is assumed that the driver is either interpreting information from the roadway or IVIS device.

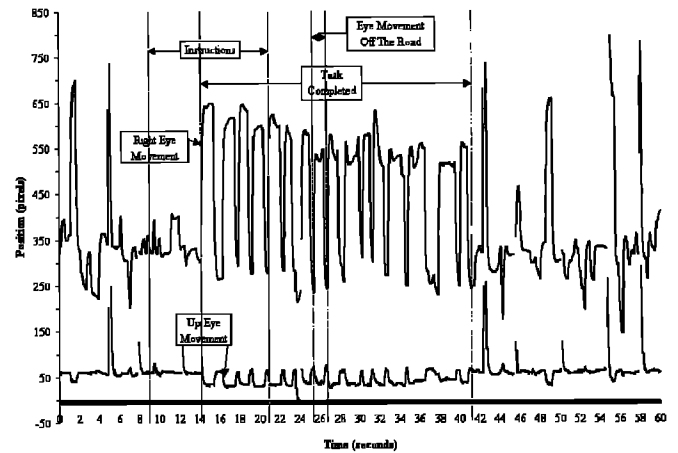


Figure 2: Horizontal (top line) Vertical (bottom line) eye movements plotted against time during the rear view mirror task

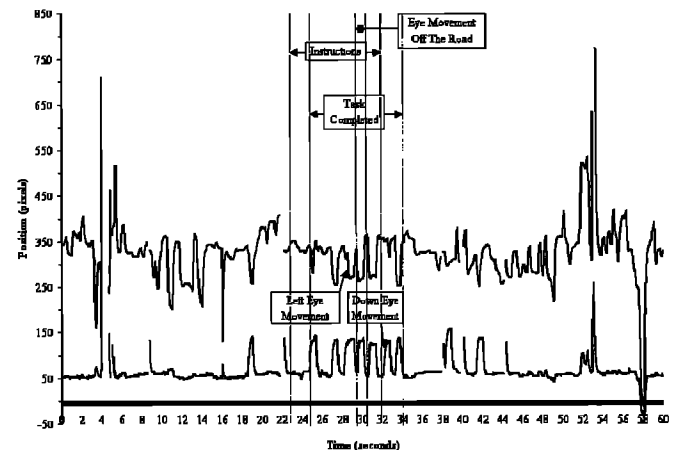


Figure 3: Horizontal (top line) Vertical (bottom line) eye movements plotted against time during the odometer task

Movement times and the influence of peripheral vision are currently omitted from this preliminary analysis for simplicity. The elimination of movement times could have some effect on glance times, since a slow movement would be better classified as part of the transition as opposed to a glance. For the radio task illustrated in (Figure 1), it is possible to construct a table, identifying where the eyes are directed during the task. Glances can be characterized as either on road or off road glances. The data corresponding to the radio change task is illustrated in Table 1. Glances can then be used as an indication of how often a driver's eyes are not on the road. Table 2 summarizes the glances for the radio, rear view mirror, and odometer tasks. The data seems to verify the, 1.6 second rule discussed in [Wierwille 1993], since all but four glances for all three tasks were under the limitation, and only one glance for 2.32 seconds exceeded 1.6 seconds for more than 0.08 seconds. Without safety matrixes it is difficult to discuss how the driver is affected by different patterns of glances. However at 25 MPH the 2.32 second glance would represent no direct fixation or smooth movement to

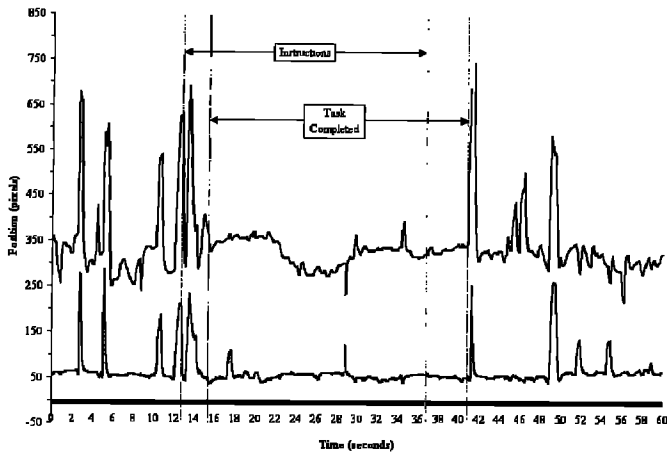


Figure 4: Horizontal (top line) Vertical (bottom line) eye movements plotted against time during the cognitive hand held phone conversation

the roadway for a distance of 85 feet, raising some basic questions of safety that cannot be answered. Glance measurements cannot be completed for the cognitive task since it would represent one long glance to the roadway. Similarly cognitive effects of the radio, rear view mirror, and odometer tasks cannot be included in the analysis. As in the case of the cognitive phone conversation, a calculated “normal” eye movement pattern could allow for a further understanding of the cognitive effects of these tasks.

Glance	Road Location		Road Location		
	On	Off	Glance	On	Off
1		1.64	16	0.34	
2	1.40		17		1.26
3		1.44	18	0.32	
4	0.84		19		1.00
5		1.38	20	0.46	
6	0.36		21		1.06
7		1.44	22	0.36	
8	0.30		23		2.32
9		1.16	24	0.54	
10	0.28		25		0.44
11		1.10	26	0.44	
12	0.32		27		0.92
13		1.18	28	1.40	
14	0.36		29		0.82
15		1.22			

Table 1: Glances for the radio task

3.2 Problems Encountered When Analyzing Eye Movement Data

Traditional methods of analyzing eye movements have focused largely on separating fixations from saccades based upon velocities, aggregation of consecutive points with duration minimums, and digital filtering [Salvucci 1999]. In a driving situation, smooth movements are also present and these methods would need to be modified to be useful in the general case. Methods of separating fixations, smooth

Measure	Radio	Mirror	Odometer
Task completion	26.12	26.56	9.24
Off the road	18.38	18.72	5.9
Max off the road	2.32	1.68	1.16
Average off the road glance	1.23	1.17	0.84
Average glance	0.90	0.86	0.71
Glances to complete task	15	16	7

Table 2: Summary of glances for the radio, rear view mirror, and odometer task

movements, and saccades, probably can be completed with a velocity threshold. The velocity of saccadic movement is always significantly larger than that of a smooth movement. A method based upon this type of separation is discussed in [Sauter et al. 1991].

Once a separation of smooth and saccadic movement is made another problem arises. If a tracing program is to map these movements to a cognitive process model, an understanding of the environment the subject is immersed in is required. In the case of a car driver, the environment is continuously changing, making it difficult to identify what is actually occurring, even if it is possible to identify where the subject’s visual attention is focused in a coordinate space automatically. Manual mapping is one technique commonly used to identify the scene. In manual mapping a human operator determines, from a video recorded during the test, what is actually occurring. In addition to the dynamic scene, head movements further complicate the analysis of eye movement data recorded using a head mounted eye tracker.

If a head mounted eye tracker is used, recorded data only represents the eye movements in relation to the subject’s head. In many situations a reference to the vehicle or outside space is desired so some calculation of the gaze path needs to be made. To calculate the gaze path some combination of head and eye position is required. Some eye tracker models are available with an optional head tracker to eliminate the head movement problem. However, these systems can be problematic in vehicles because of their use of magnets.

Difficulties with head movements when using a HED are one reason for their limited use. In situations where a head tracker can not be used, characteristics between head and eye movements maybe useful in separating out the head movement component of the gaze path. In [Stern and Ranney 1999] head movement is shown to be dependent on eye movement. Land [Land 1992], discusses the semi-predictable relationship between fast moving saccadic movements and slower head movements. When both the eyes and head receive commands to turn, an eye movement occurs quickly with the head following slowly, if free to do so. In situations where the head is not free to move, additional movement is added to the eyes, resulting in the same line of gaze [Land and Horwood 1996]. Stern and Ranney [Stern and Ranney 1999] describe two types of head movements, predictive head movement, where the head movements usually precedes the eye movement, and reactive head movements where the eye movement “lags behind the head movement”. Predictive head movements usually occur in situations where we anticipate looking at something in our peripheral, while reactive head movements occur when we do not anticipate looking. Other methods have been developed for identifying head movement, including video analysis techniques using face tracking ([Matsumoto and Zelinsky 2000] and [Park and Lim 2001]) and a more complex light projection system [Schumacher and Korn 1983]. Future work on separating

head movements could include action recognition algorithms similar to those proposed in ([Bobick 1996] and [Laya 1998]). The work in [Laya 1998] aims to develop an image processing solution to the head movement problem. Schill et al. [Schill et al. 2001] look at methods for automatically detecting regions of interest in images using a complex learning based system based upon eye movements, while disregarding the actual head position.

In order to further understand what effects distracting tasks have on the driver, some understanding of what is considered "normal" driving is needed. Such a measure is inherently difficult to calculate in a real road setting since the environment is constantly changing. The problem is akin to the steady state problem in random process. However, in the case of drivers, it may be possible to estimate "normal" eye movements in an artificial environment where the road is straight, with oncoming cars. However here too it is easy to imagine the number of possible derivations that could be discussed to describe what a driver would be expected to look at. In a situation with an oncoming car approaching at 25 MPH, the driver needs to give the less attention to the approaching car than at 40 MPH since unconsciously the driver knows things are happening slower. While signs on the side of the road require quick glances that may happen with some probability etc.

4 Conclusions

This paper demonstrates how various eye movements can be collected and analyzed to compare a driver's performance with a variety of in-vehicle tasks. Conclusions verify some basic measures that have already been published in the literature. Eye movements for the radio, rear view mirror, and odometer tasks all show patterns of time sharing by drivers. Attention is divided between the tasks of driving and the secondary task, switching back and forth between them. The basic method of analysis demonstrated here shows only how a driver divides attention, cognitive effects of the task cannot be analyzed using this method. Results also concur with the apparent maximum glance time of approximately 1.6 seconds off the road as discussed in [Wierwille 1993]. In the three test cases shown only four violations of this rule occurred for the 38 glances off the road and only one of these violations exceeded the rule by more than 0.08 seconds. The small variation may relate to how movement times were assumed to be negligible. The one glance for 2.32 seconds during the radio task is however well above the tolerance limit. If the driver was observing the posted speed limit of 25 MPH, such a glance off the road represents traveling a distance of about 85 feet. Although it is tempting to conclude that traveling 85 feet without looking directly at the road is a dangerous driving practice, additional work is needed to support this hypothesis, and to develop a similar matrix for the effects of cognitive distractions.

The decrease in eye movements shown with the cognitive task concurs with what has been published, and the basic principal of visual tunneling that occur under cognitive load. The dangers involved with the cognitive task are shown to continue past the end of the phone conversation, agreeing with the situation described by [Redelmeier and Tibshirani 1997], that the risk of a cognitive conversation is still higher than "normal" after conversation ends. Since the cognitive task is represented as a single glance at the roadway, it may also be interpreted as an unsafe driving practice. It is however a more difficult problem to identify a level of risk from the data collected in this study without further methods of

comparing some measure of "normal" driving. Without a "normal" data stream difficulties also exist identifying if the effects of the task are completely eliminated.

5 The Future

To further develop driver prediction models for real-time warning systems and advanced modeling systems, fast methods of analyzing human eye movements are needed. The next logical step is to develop matrix for interpreting and evaluating eye-movements as a method of predicting a driver's intent. Since human eye movements are assumed to follow a shift in attention, this method shows the most promise for predicting driver actions. Future vehicles could easily be fitted with eye tracking equipment, monitoring a drivers fixation patterns, thus preventing unsafe distractions.

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