# Multi-Modal Vehicle Display Design and Analysis 

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#### Abstract

There is increasing interest in systematically studying the risks encountered while driving. In some cases, the focus is on potential risks such as those associated with the use of in-car devices (e.g., mobile phones, radio, navigational displays) or the effect of substances such as alcoholic beverages or medications. In such studies, the objective is in determining whether there is a decrement in driving performance that could lead to an increase in the probability of an accident, i.e. turns a safe driver into an unsafe driver. Another type of study involves the evaluation of the potential benefits/risks associated with the use of corrective/assistive devices (e.g. hand controls, vision enhancement devices) that might enable individuals with disabilities to drive. Here, the primary interest often is in determining the device in question produces an increment in driving performance that could lead to a decrease in the probability of an accident, i.e., turns an unsafe driver into a safe driver. In both of the above cases, it is ultimately important to address the issue(s) through on-road testing. However, because of the different aims of the two types of studies, care must be taken to ensure that the design of the test route(s) and driving tasks are deliberately biased to maximize the likelihood of answering the critical questions. This report, submitted in conclusion of Grant 536161 of the University of Rhode Island Transportation Center, first discusses issues arising in the design of on-road studies. Two examples are given to illustrate the different approaches used in route and testing protocol design. The first example considers the special design elements to evaluate the impact of in-vehicle mobile phone use by normally-sighted drivers on overall driving performance. The second example considers the special design elements of a road test course to evaluate the effectiveness of vision devices as driving aids for visuallyimpaired people. The second part of the report presents details of an on-road study of driver performance using eye-tracking data.


# SECTION $1^{1}$ : DRIVER PERFORMANCE EVALUATION: CONSIDERATIONS UNDERLYING SELECTION AND DESIGN OF ROUTES 

### 1.1 Introduction

Advances in vehicular technology have made driving safer now than ever before. However, this increase in safety has been offset by increasingly ageing driving populations, longer daily travel times and widespread use of mobile computing and communication devices while driving. Although in-vehicle devices such as the radio, climate controls etc. have been located on automobile dashboards since the first prototypes, it is possible that these distract the driver. In spite of the lack of strong supporting evidence, there is not much concern about the risk incurred by the routine use of these devices while driving. The current controversy and concern is centered on the risk posed by the use of recently introduced in-car devices such as cell phones, navigation systems etc. Another impact of the advances in technology relates to the level of assistance that can be offered to drivers with impairments. Vehicles customized for disabled individuals are increasingly commonplace. In most cases, these are vehicles with controls such as pedal operation, seat configuration etc. rearranged to suit the driver. However, when the impairments are vision related the accommodation is not as simple. In most interactions of the driver with the environment, the visual senses are the primary sensors, and vision impairments may result in substantial limitations or restrictions of performance. When working on assistive devices for these impairments, it is important that adequate testing be done in actual (on-road) conditions for any remedial evaluation.

Early investigations on the effect of in-vehicle devices focused on minimizing the effect of interface configurations and on structuring the information needs for specific tasks (Alm (1993) and Alm \& Nilsson (1995)). Epidemiological methods have also been used in identifying safety effects from crash data in Wang, Knipling \& Goodman (1996). Tijerina, Parmer \& Goodman (1998) used commercially available navigation systems in a vehicle on a test track to evaluate the distraction caused by entry of destination data, and found that destination entry in commercially available navigation systems takes longer then the time required for the use of controls, the radio or a cell phone. Many of the studies rely on laboratory based test rigs for assessing changes in behavior, and by inference, the risk, caused by the use of invehicle devices. In laboratory test rigs range from rudimentary simulators to sophisticated immersive vehicle simulators. The former is typically one where a video captured from a moving vehicle is displayed on a screen. Advanced vehicle simulators include vehicle cabs that are surrounded by screens, and the vehicle controls of the test rig produce effects that mimic the behavior of a vehicle in similar conditions. In spite of the substantial cost difference between the entry level simulators and the high end systems, it is not clear that any particular configuration is superior in inducing high fidelity responses from subjects.

[^0]In some cases, evaluations of driving performance have been conducted on test tracks with controlled (or no) traffic. Examples of this include navigation systems (Antin, 1993) and age and vision (Wood, 1999). Green (1999) discussed the limitations of simulation studies, and the extension of such studies to on-road settings, and concluded that the ability to perform on-road testing was limited because navigation tasks may be classified as "too risky".

Although simulator and test track studies may pose a lower risk as compared with on-road studies, the absence of test results from on-road conditions raises the bar for asserting the risk associated with these tasks, and the resultant ambiguity often leads to delaying or weakening legislation that should be enforced to improve driver safety. The legislative developments relating to use of cell phone while driving in the US can serve as a case study on this topic. In other cases, such as the testing of assistive devices for visually-impaired drivers, the need for on-road testing may be mandated by legislation. When on-road testing must be conducted, extreme care must be taken to anticipate and avoid exceptional conditions that may arise during testing. This report describes some of the issues that must be considered in the design of on road test routes for driver testing. General design issues are considered and then special design elements are discussed for two specific studies: the impact of cognitive or other distractions (e.g. mobile phone use) on driving performance of normally sighted drivers and the effectiveness of vision devices as driving aids for the visually impaired.

### 1.2 Methods of Driver Performance Evaluation

On-road tests for assessing driver performance require tracking of one or more metrics related to the performance of the driver. The performance under "normal" or "un-distracted" conditions is compared with "assisted" or "distracted" driving conditions. The following is a categorization of the metrics typically used for driver performance measurement:

### 1.2.1 Vehicle Metrics

These metrics relate to vehicle position and orientation, and include lane position, driving speed, vehicle steering angle, brake distances etc. Tracking metrics of this type requires vehicle instrumentation, although the development of sufficiently accurate GPS systems has now greatly facilitated the task of data collection.

### 1.2.2 Biological Metrics

These are computed by tracking biological parameters such as heartbeat, blood pressure, eye-positions, pupil diameter, blinks etc. Improvements in instrumentation have now made it possible to track these metrics with portable devices in-situ. However the data analysis task remains formidable, particularly when tracking driver eye movements, where the eye position data has to be interpreted in conjunction with the scene video.

### 1.2.3 Cognitive Metrics

These metrics relate to the locus of attention or cognitive workload of the driver. Estimates of these metrics are usually obtained through interaction with the driver to assess the performance of a driver under different conditions. Examples of such metrics include detection of traffic sign or other driving relevant item, time to perform a given computation, and the accuracy in committing items to memory. Usually such metrics require interaction with the driver, usually by an accompanying investigator.

Because of the obvious interference that the process of evaluation itself causes in the examination of metrics of this class, they should only be evaluated sporadically, and with sufficient spacing between successive evaluations to maintain independence.

### 1.2.4 Subjective Metrics

This includes evaluations of driving performance that are difficult to assess by automated means, or do not include cognitive issues of driving workload. Interactions with other drivers, responses to pedestrians, obstacles etc. would be evaluated by such measures. Subjective metrics are usually assessed by observation, and scoring schemes have to be designed with great care to ensure a uniform standard of evaluation is applied across different drivers and evaluators.

The classification above is not intended to be orthogonal - i.e. there is possibly significant correlation between the metrics in and across the categories. The primary issues concerning these metrics when designing a route are the sampling frequencies and the locations where they should be assessed. Biological metrics and vehicle metrics can be sampled continuously and require little to no intervention. However, because of interface issues, the maximum run length and the cumulative error may limit the duration of each segment of a drive, requiring an interruption to recalibrate and reset sensors. Cognitive and subjective metrics may require proper spacing because of the possible interaction of successive measurements.

### 1.3 DESIGNING TEST ROUTES FOR EVALUATING DRIVER PERFORMANCE

Routes designed with the goal of evaluating the impact of cognitive distractors on driving performance of "normal" or un-impaired drivers differ from routes designed to evaluate the effectiveness of vision devices as driving aids for the visually impaired. In the former case routes should be designed to take the driver through normal and exceptional circumstances in a controlled manner whilst collecting data to compare the metrics of interest against baseline or standard or normal levels. In the latter, the goal is to evaluate the performance of an impaired driver to compare his/her driving performance against an acceptable (normal) level of performance with and without visual aids. Regardless of the specific goal, several issues common to both route design processes are discussed below:

### 1.3.1 Route design preliminaries

Any route design involves selection of starting, intermediate (where data is to be collected) and ending points. Data may be collected continuously from the start to the end - however, this can complicate subsequent processing, especially when video data is collected as well. Other factors involved in determining the length of period for which the data is collected include the spacing of tasks that are to be given to the subject. In general, each data-collection run starts with an instruction period, and often, a calibration period. Instrument calibrations can be time consuming, especially if the calibration has to be done in the test vehicle. The number of tasks is limited by the length of the route, and the need to replicate tasks under different road conditions. The use of Global Positioning Systems (GPS) and automatic tracking programs can greatly facilitate in the initial planning of the route.

### 1.3.2 Length of task durations

For each task, the required length of the testing period is the sum of the time required for the instructions and time that the subject may require for responding. If the location where the instruction is delivered is kept the same, the time and approximate
distance that a vehicle moves during this period will be the same. However, the task execution time can vary substantially: when response time is small it is approximately constant; but when response time is large it is variable. In general, the variability of the task execution time is related to the mean task response duration. Pilot runs can be made to determine the variance, and a limit (e.g. $3 \sigma$ ) within which the task execution is expected. Major intersections, stop signs, school zones, restricted driving zones should be excluded from this limit.

### 1.3.3 Visibility for task presentation

Tasks should be located on the test route with clear visibility of the oncoming roadway for the duration of the task. Thus, regions with tight turns or hills that present blind spots should be avoided unless specifically included for testing purposes.

### 1.3.4 Congestion and additional traffic interaction

The congestion of a roadway may also significantly affect a driver's behavior. Regions of congestion can be identified as part of the path evaluation and can be used to compare the driver's behavior under certain conditions with non-congested sections of roadway. If congestion is indeed a factor to be considered in route design additional traffic interaction should be included. In some situations the time and direction of travel may need to be adjusted to place subjects on sections of roadway with similar traffic densities. The day of the week may need to be taken into consideration since traffic on Fridays often increases at an earlier time than other days.

### 1.3.5 Intersections and the need for stop signs and traffic lights

Stop signs or traffic lights also need to be considered explicitly during the routeplanning phase. If the purpose of evaluation relates to identifying differences in a driver's behavior through different types of intersections, a few additional issues should be taken into account: first, if there is a certain level of congestion that needs to be present in the intersection, the time of day when the experiment is to be completed must be adjusted; second, if the driver needs to stop at a traffic light to test a task completion, some method of triggering the traffic light as the vehicle approaches must be negotiated with the appropriate roadway authorities; third, directions given to the subject describing where to go must be presented at a reasonable distance from the intersection to allow for sufficient execution time. Routines for coping with contingencies should be put in place prior to the study.

### 1.3.6 Directions to subject and investigators

Directions given before the test can either fully describe the route or provide an overview as a method of familiarizing the subject with where they will be traveling. In situations where directions are only given once, the route must be simplified to where the subject can easily take notes or remember the path of travel. Contingency plans need to be developed for missed turns. If directions are given in-route, each step must be reduced to components simple enough for the driver to remember, and cues should be given to the accompanying investigator for prompting the driver. When possible, the use of GPS coordinates to trigger automated direction playback is recommended. Also important is a standard method for communicating with the test driver during the drive - the use of a uniform method for communicating will reduce driver anxiety and augment safety.

### 1.3.7 Error reduction

The errors encountered in an on-road driver performance evaluation can be divided into three categories based upon cause: driver errors, experimenter errors and recording errors. Driver errors occur when a driver fails to perform some task as directed. These cannot be eliminated, but clear presentation of directions can reduce these. When some error does occur, a procedure for correcting it must be implemented. Options for marking the data records should also be provided to clearly identify the sections corresponding to the error. Experimenter error occurs when a task or direction is not presented as indented. Experimenters should be trained for the tasks they will be responsible for during each stage of an on-road experiment. Hesitation in presenting tasks may transfer uncertainty to the subject, reduce safety and interfere with the accuracy of the experimental results. Checklists or reminders should be prepared. When experimenters do make an error a procedure needs to be in place for correcting it. In some situations if an experimenter error conflicts with the directions given to the driver, a procedure for reconciling should be designed in advance. Recording errors can be avoided through testing and planning. In general, more problems will be encountered with more complex recording equipment. Electronic devices need to be tested for interference with other devices, and for accuracy under the range of environmental conditions that they will be used. The procedures for starting, ending and calibrating recordings must be identified to provide clear markers in the data collected, any variations must be noted.

Other issues that should be considered include speed limits, signs, number of lanes, road conditions, subjects familiarity with roads, bridges or tunnels, road lights etc.

### 1.4 Evaluating cognitive distractions by tracking eye movements

When selecting routes for assessing the performance of drivers by tracking eye movements, an important issue that requires consideration is the road direction and time of day of the test. Once a possible route or set of routes has been identified, the angle of sunlight at different times of the day should be taken into account. The vehicle should be oriented to minimize the amount of incident infrared (IR) radiation inside the vehicle. If the IR levels are high, some eye trackers cannot accurately track the location of the pupil. Even with the use of an IR shield, reflections of IR off the vehicles internal surfaces can cause problems. Test trials should be completed during various periods of the day. When possible, roads with dense foliage should be selected to provide additional insulation from IR.
When evaluating distraction, the use of a driver's own vehicle is recommended to reduce the additional processing load of driving in an unfamiliar vehicle. Subjective metrics can be assessed in own-vehicle or instrumented vehicles.

The influence of driver comfort should also be evaluated to ensure that the data collected is not exceptionally influenced by driver fatigue. As an example, if the level of accuracy required is high, head mounted eye tracking devices are necessary for measuring eye positions. However, these can limit the length of time that a subject can drive comfortably. Frequent stops and recalibration points must be arranged along the route to improve driver comfort and data collection success.

### 1.5 Effectiveness of vision devices for visually-impaired people

In this section issues related to the design of an on-road test route for investigation of driving performance of visually-impaired people will be discussed. The following impairments and assistive devices are considered:

1. People with reduced visual acuity, driving with and without bioptic telescopes;
2. People with hemianopic visual field loss, driving with and without peripheral prisms.

Design criteria ensure that the route will contain a representative range of normal driving tasks, as well as specific tasks that are expected to be difficult for people with each type of vision impairment, and will be sensitive to evaluating performance with and without each vision device. The aim is to have design criteria that can be easily implemented to produce multiple versions of a route (for assessments with and without a device), which are as similar as possible and can be implemented at several study locations. This approach enables the use of the same route design for more than one type of vision impairment.

### 1.5.1 Type of vision impairment and relation to route design

Difficulties encountered by visually-impaired drivers are expected to vary according to the type of vision impairment. Patients with reduced visual acuity have difficulty seeing details, for instance reading road signs and seeing objects at a long distance, however they usually have normal peripheral vision. In some jurisdictions they are permitted to use bioptic telescopes when driving (e.g. in 34 states in the USA: Peli, 2002). The bioptic telescope provides magnification to enable small details to be seen at a normal approach distance, and is used for reading road signs and scanning ahead for hazards (Kelleher et al., 1971; Corn et al., 1990, Peli et al., 2003). Specific sign reading tasks are therefore included in the route design.

By comparison, people with hemianopic field loss have normal visual acuity, but a restricted visual field (they lack half of the field on one side in both eyes). As they have a blind (non-seeing) hemi-field, they might miss objects in this field unless they scan effectively while driving. We planned to evaluate the effectiveness of peripheral prisms as a driving aid for people with hemianopia. Peripheral prisms provide expansion of the field into the blind hemi-field, thus increasing the probability of detection of objects on the blind side (Peli, 2000). As the blind hemifield may be on the right or the left, an equal number of right- and left-sided tasks are included in the route design. Hemianopes may exhibit unsteadiness of steering (poor lane control) and difficulties with correct lane positioning; these aspects of driving performance are therefore incorporated in the design (Szlyk, 1993; Tant, 2002).

### 1.5.2 Route design specifics

The route design comprises a pre-test section (about 10 to 15 minutes) and a scored test section of about 30 to 45 minutes on-road driving. The purpose of the pre-test section is to enable the subject to become familiar with the car (while driving around a parking lot or quiet roads) and for the driving instructor to ensure that the subject demonstrates adequate vehicle control and driving before proceeding to the scored section of the route. The scored section contains a variety of types of road including single and dual carriageway and motorways (highways), and intersections with and without traffic lights, stop and yield signs and roundabouts. The roads include sections with well and poorly marked edges, straight sections and bends, quiet and
moderate traffic density.
The following scored tasks are included in the test section, with about one scored task every minute:

- Lane control: straight sections of road to evaluate steadiness of steering and lane position
- Lane changing: on multi-lane road, to evaluate lane changes to left and right
- Curve taking: an equal number of right and left bends to evaluate steering in curve taking
- Turns: an equal number of right and left turns at intersections with and without traffic lights, stop and yield signs
- Crossing intersections: going straight across intersections with and without stop and yield signs
- Roundabout: entering, driving round and exiting roundabout
- Parking: move forwards into and reverse out of designated parking space
- Reading signage: call out road signs seen along specific sections of road and find specific streets by street name signs
- Motorway (highway) driving: merging, exiting, and overtaking (also including one section of lane control, reading signage and lane changing).
The design also includes at least two locations where it is possible to pull off the road (to enable completion of scoring, if necessary) and planned "recovery" routes so that if a subject takes a wrong turn, minimal time will be taken in returning to the original route. In addition the route is designed so that there will be sufficient time for driver instructions to be given prior to each maneuver and driver response or action to be taken safely.


Figure 1.1: Example of a task score sheet (find a specific street and complete a left turn at the following street).

### 1.5.3 Assessment procedures

Based on route design and the aspects of driving performance to be evaluated, a template score sheet was developed for each of the main scored driving tasks (i.e. turn, change lane etc). Once an on-road route is determined, these general template score sheets are then made route specific, by the addition of road and intersection details, and compiled into a booklet according to the sequence of driving tasks along the route.

Driving performance is scored using a series of items listed in the middle column (Figure 1.1), while instructions to be read to the driver are in the first column and a depiction of the road layout is given in the last column. The specific driving skills (items) to be scored for the maneuvers are: lane position, gap judgment (the gap or distance between the test vehicle and vehicles from one or both sides when crossing or moving into their lane), speed (whether speed is appropriate for the maneuver), path (the path taken when going around a curve), steer steadiness, spacing (following distance) and speed match (when merging or overtaking). Each of these items is scored on a five-point scale. Scores of 1-3 represent various levels of unsatisfactory performance (from 1, driving evaluator had to take control of car, to 3 unsatisfactory but does not compromise safety), while 4 and 5 represent increasing levels of satisfactory performance. To aid completion of a score sheet, the boxes for unsatisfactory scores (1, 2 and 3 ) are shaded grey (Figure 1.1). An additional score is also required when an unsatisfactory mark is given. This score is based on a binary choice, recorded in the boxes to the right of the 5-point scale, indicating "excesses" in performance e.g. if the lane position is too far to the left/right, gap judgment is too small/too big (Figure 1.1). In addition other items are scored Yes/No, such as whether the signal indicator is used (signal), whether the subject scans before performing a maneuver (search), whether the subject obeys traffic signals or reads traffic signs.

In addition to the task score sheets, a "global" score sheet was developed to evaluate overall driving performance along the whole route (not just the scored tasks). This evaluation is performed at the end of the test ride and includes interaction with other traffic, vehicle control, anticipatory skills, adjustment of speed to traffic conditions, reaction to unexpected events and an overall rating of driving performance, including the question "Would you give this person a license?".

Two evaluators travel in the dual control vehicle. The primary evaluator, who sits in the front passenger seat, gives instructions to the driver and is responsible for safety (taking control of the car if necessary). $\mathrm{He} /$ she only completes the global score sheet. The second evaluator, from the back seat, completes each task score sheet (immediately after each task is performed) and the global score sheet.

### 1.6 Discussion and Conclusions

This paper discusses the design of test routes for evaluating driver performance. Two different types of on-road driving evaluations have been presented - the first for assessing the impact of distractions on drivers, and the second for evaluating the driving capability of drivers with and without vision assisting devices. The designs for these two on-road evaluations were set up independently by two groups of investigators. In addition to the identification of common features involved in the route design process for both evaluations, several noteworthy lessons emerged from the comparison: 1 . When objective methods such as eye movement tracking are used for assessing driver performance, care must be taken to ensure that the data collection
process is robust. Robustness can be attained by proper vehicle preparation (instrumentation), automation of task presentation and data recording, calibration and route optimization. These methods are more suitable for evaluating the performance of normal drivers, and can be used to help identify exceptional behavior under test conditions. 2. Subjective scoring methods should be used for assessing performance when the number of metrics to be evaluated is large, and an integrated evaluation is desired over specific route sections. These methods are more suitable for evaluating the performance of impaired drivers under normal or usual driving conditions. However, better data may be obtained by integrating features from both methods. When subjective scoring methods are used, it may be possible to automate the collection of vehicle metrics relieving the observer from this monitoring activity. Similarly, when using objective methods such as eye movement tracking, better information about the driver's performance may be recorded by including subjective metrics vis-à-vis scoring sheets. Given the increasing intrusion of in-vehicle devices, and a growing population of drivers with impairments, the need for on road testing is likely to intensify. The guidelines suggested in this paper could reduce the testing effort and risk.

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## SECTION 2: GLANCE ANALYSIS OF DRIVER EYE MOVEMENTS

### 2.1 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 driver safety. Manual, visual, and auditory interactions are required 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 deduce. To improve vehicular safety, some method for the assessment of these distractions is required ([17], [29]). However, the exact parameters with which a minimum threshold can be defined are not yet fully understood ([11], [7]). A recent study [34] 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 ([32]) 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 ([13], [3]). 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 averse, they may not be 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 [22], is summarized below.

### 2.1.1 Existing research into the distraction problem

It has long been recognized that an overload of information processing capacity causes problems with driving performance [12]. Existing research provides a number of examples of overload. In [1] it is demonstrated that concurrent performance of an auditory task impairs judgments of whether the car can be driven through a narrow gap. In [8] 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 ([13], [3]) have an impact upon the driver's attention in different ways. In [13] 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 ([16] and [3]). The relative risk of driving with a cell phone has been reported as being comparable with the hazard associated with driving while intoxicated [21]. It has also been shown that the risk associated with a phone conversation while driving does not end with the call ([21]), 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 report focuses on the use of eye tracking methods to monitor how various distractions 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 through 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 report.

### 2.1.2 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 point-to-point 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 degrees per sec [2]. The time between saccades is dependent upon the time required to perceive 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 place 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.
In many cases eye movements are assumed to be predictors of attention. An eyetracking systems can therefore be used to collect information about how a driver responds to different situations on or off the road [20]. Two different models foreye movements and attention are described in [9]. 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 [20]. Saarinen [25] 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 [27]. 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" [19]. In the past, researchers have used eye movements as an insight to person's thoughts and intended actions [13]. More recently, the focus has shifted into modeling behavior patterns based upon eye movements [28]. In either case information about where a subject is looking must be collected at high sampling rates, to capture any sudden changes in a person's actions.
Eye movements recorded at high sampling rates can give important clues to driver 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 [10] 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 [26]. 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" [26]. Salvucci ([28], [26]) 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 in 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 continuously tracking other vehicle, signs, and objects outside the vehicle using smooth movements. To quantify the safety effects different in vehicle devices an understanding of how a driver searches the visual field without any
distractions must be understood. Using this developed understanding of the visual scene drivers can then be asked to complete some secondary tasks that can be used as a method to compare changes that occur in the driver's behavior patterns. Individual differences, and the type of roadway are expected to play significant roles in these behavior differences. Currently no method exists to quickly analyze the large sets of eye movements that would be required to develop these comparisons.
To develop new automated method of analyzing driver's eye movements an understanding of visual search patterns that are likely to be exhibited needs to be developed. 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 [31]. The relatively low sampling rate of a 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 effectively search up to three targets per second [15]. 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 [24]. Multitasking or 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 [33]. 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 [23]. 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. Drivers have naturally developed a safety mechanism to counteract this problem. Wierwille [33] found that drivers limit the amount of time focus is directed off the road for comfort, to a maximum of approximately 1.6 seconds. Using this naturally developed comfort limit it is possible to consider what glances are outside the average drivers comfort limit. With 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 scenes, experienced drivers exhibit a larger number of eye movements with decreased fixation length [4]. This practice leads to other interesting questions on the possibility of a relationship between the number of continues glances and driving safety.
Other problems can be identified in a driver's 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" [35]. A relationship between the size of the visual field and workload has also been noted, when too much information is being processed the useful field of view contracts to prevent overloading of the visual system ([18], [14]). In addition, a reduction in the mean gaze duration under these circumstances can be
also found [14]. The reduction in visual field size can be related to two separated phenomena. Tunnel vision, which is defined as a reduction in aperture angle of the visual cone, and second, a general decrease in peripheral visual performance which is independent of the visual cone angle [18]. When drivers are affected by either of these changes they must rely on a greater number of shorter fixations to detect and acquire information from targets ([14], [6]). Crundall et al. [5] concludes that in these situations slower reaction times result. To develop a better understanding of driver behavior patterns, an on the road driving study, using a commercial eye tracker as a method of determining where a subjects attention is focused, was conducted. To further understand the effects that distractions have on drivers as well as verifying the results of some previous experiments the subjects were instructed to complete a variety of common driving tasks.

### 2.2 TRACKING DRIVERS EYE MOVEMENTS IN AN ON-THE-ROAD SETTING

The preliminary use of eye tracking for studying drivers eye movements was discussed in [24], where an investigation into the gaze pattern of distracted drivers on rural roads was completed. At specific points during the experiment the subject was confronted with several distractions played back from a pre-recorded CD by one of the investigators. The distractions that each subject was presented 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 rear view 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).

Results from the study showed that distractions could be broken down into two major categories. First a glance type distraction, which results in the subject glancing between the roadway and some secondary task for different periods of time. Two categories of these distractions can be identified, those that are required for safe vehicle operation such as glances to the rear view mirror or dashboard as illustrated in Figures (2.1-2.2), or glances not required for safe vehicle operation such as a glance to the radio illustrated in Figure 2.3. While glance distractions can be easily observed having an effect on the operation of the vehicle the second type of distraction can be more difficult to identify. Cognitive distractions, as illustrated in Figure 2.4 exist in situations where the subject is engaged in some secondary cognitive activity besides the driving task. While cognitive distractions may be considered as a second type of distraction there may be some direct effects visible in glance distractions. The association can be best understood by considering the concept of a control.
In the Figures $(2.1-2.4)$ the pattern of eye movements before a task is given to the driver, can be regarded as controls. The classification can be made since the subject has no indication when the instructions for a task are to begin, thus the period before the task is presented can be considered independent to the task. However, it is difficult to classify any of the recorded movement as being representative of a "normal driving" glance pattern. The problem is best explained by considering the non-
stationary state of the roadway. At every instant of time differences in the roadway occur based upon many non-repeatable parameters, making this "normal" classification difficult. It is trivial to conclude that some searching of the visual scene and monitoring the vehicles controls should be characterized as "normal driving", but there will likely be some dependence on the road conditions. If any comparisons are completed it is best to make these comparisons with controls taken just before the task is presented, since this period of time represents the closest environment to the task. If Figures ( $2.1-2.3$ ) are considered it is easy to observe the scanning movements occurring before the instruction periods. The scanning movements are not visually identifiable during the completion of the instructed tasks. The observation can be used as a verification that some interaction between the two types of distracting activities is occurring. The phenomena is however difficult to identify without a more precise understanding of the cognitive requirements of tasks such as changing the radio station, and observing the following vehicle.


Figure 2.1. A driver's eye movements during the rear view mirror task.


Figure 2.3. A driver's eye movements plotted against time during the radio task.


Figure 2.2. A driver's eye movements plotted against time during the odometer task.


Figure 2.4. A driver's eye movements plotted against time during the cognitive hand

The instruction period, task completion period, and an individual eye movement off the road are illustrated in Figure 2.3 for a subject completing the radio task. An observation of the figure easily shows see how the drivers eye movements were following the time-sharing model, moving between the roadway and radio until the task was completed. 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 while some action is completed. The fixation is followed by a movement back to the forward view up and to the left of the radio i.e. (the horizontal and vertical positions decrease), and the process repeated. The rear view mirror task, Figure 2.1 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. While the odometer reading, Figure 2.2, shows more of just a one dimensional movement to the dashboard. Thus when a 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 periphery but not directly in front.
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 i.e. end of the instruction period. Relating to the situation described in [21], 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 devoting attention to a cognitive task.

### 2.3 Analysis

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. A detailed analysis of driver's glances can be completed for the radio, rear view mirror, and odometer tasks. While the initial model detailed in [1] disregarded movement and search times, this analysis includes these important sojourns, since during the saccadic movements no visual information can be perceived. The influence of peripheral vision cannot be estimated in the analysis since eye tracking cannot locate where peripheral information may be in the process of being acquired. In each of the glance type distractions illustrated in Figures (2.1-2.3) a fixation on the roadway and on the distraction as well as the movements that occur between these fixations have been manually identified. Manual identification included a comparison of the point-to-point velocities, general movement direction and recorded scene data. The data is summarized in Table 2.1 for a subject completing the radio task, as plotted in Figure 2.3. Table 2.1 shows each glance characterized as either on or off the road. Intervals between each glance are characterized as movement or search times. A data recording showing a single glance to the road, off the road, and the movements between them is plotted in Figure 2.3. A summary of the glance patterns for five subjects performing the radio task are shown in Table 2.2, while Table 2.3 and Table 2.4 show the statistics for the rear view mirror, and odometer tasks respectively.

It is important to note that the tables do not represent the same five subjects for all tasks. This is because the raw data captured was extremely noisy, and thus different subjects were required to develop the five samples used in these statistics. The variability between subjects is assumed not to have any bearing on the overall outcome of the summary.

| Step | Duration | Step | Duration | Step | Duration | Type |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | 0.46 | 17 | 0.28 | 33 | 0.38 | Movement |
| 2 | 1.14 | 18 | 0.88 | 34 | 0.88 | Off-Road |
| 3 | 0.30 | 19 | 0.18 | 35 | 0.24 | Movement |
| 4 | 1.12 | 20 | 0.12 | 36 | 0.10 | On-Road |
| 5 | 0.24 | 21 | 0.22 | 37 | 0.28 | Movement |
| 6 | 1.24 | 22 | 0.84 | 38 | 0.68 | Off-Road |
| 7 | 0.18 | 23 | 0.22 | 39 | 0.24 | Movement |
| 8 | 0.62 | 24 | 0.12 | 40 | 0.22 | On-Road |
| 9 | 0.34 | 25 | 0.22 | 41 | 0.32 | Movement |
| 10 | 1.06 | 26 | 0.98 | 42 | 0.72 | Off-Road |
| 11 | 0.30 | 27 | 0.20 | 43 | 0.3 | Movement |
| 12 | 0.04 | 28 | 0.18 | 44 | 0.12 | On-Road |
| 13 | 0.26 | 29 | 0.26 | 45 | 0.26 | Movement |
| 14 | 1.16 | 30 | 0.94 | 46 | 2.02 | Off-Road |
| 15 | 0.22 | 31 | 0.20 | 47 | 0.24 | Movement |
| 16 | 0.10 | 32 | 0.14 |  |  | On-Road |
| 7 |  |  |  |  |  |  |

Table 2.1 Glances and movement times for the radio task in Figure 2.3

| Measure | 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 <br> Glance | 2.02 | 1.52 | 1.8 | 1.5 | 0.96 | 1.56 |
| Total number of Off- <br> Road Glances | 12 | 11 | 10 | 12 | 14 | 11.8 |
| Average Length Off- <br> Road Glances | 1.05 | 0.82 | 0.72 | 0.74 | 0.49 | 0.76 |
| Average Movement <br> Time | 0.26 | 0.42 | 0.30 | 0.38 | 0.36 | 0.34 |
| Average On-Road <br> Glance | 0.26 | 0.56 | 0.50 | 0.61 | 0.19 | 0.42 |

Table 2.2 Summary of glances for five subjects changing the radio (s)
First an overall view of the data shows that it is consistent with the 1.6 second limit discussed in [33]. Only 2 out of 113 off road glances during the radio task and 2 out of 95 off road glances during the rear view mirror tasks exceeded this 1.6 second
threshold, with the largest off road glance recorded at 2.02 seconds. It is worth noting that the extended glances in the radio task were recorded within the last two off road glances, (i.e. at the end of the task), and one of the two glances in the rear view mirror task was the first glance. Also it is perhaps significant 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 is just under half the 1.6 second comfort limit, while the average rear view mirror glance 0.96 seconds is a little more, and the average dashboard glance 0.69 seconds.

| Measure | 1 | 2 | 3 | 4 | 5 | Average |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Total Task Time | 26.78 | 24.28 | 21.12 | 17.38 | 11.04 | 20.12 |
| Total Time Off- <br> Road | 14.47 | 7.60 | 10.64 | 9.38 | 5.02 | 9.42 |
| Maximum Off- <br> Road Glance | 1.46 | 1.98 | 1.5 | 2.0 | 1.24 | 1.63 |
| Total number of <br> Off-Road Glances | 16 | 10 | 10 | 7 | 7 | 10 |
| Average Length <br> Off-Road Glances | 0.90 | 0.76 | 1.06 | 1.34 | 0.72 | 0.96 |
| Average <br> Movement Time | 0.26 | 0.39 | 0.32 | 0.31 | 0.32 | 0.32 |
| Average On-Road <br> Glance | 0.25 | 0.98 | 0.46 | 0.60 | 0.3 | 0.52 |

Table 2.3 Summary of glances for five subjects looking at the rear view mirror (s)

| Measure | $\mathbf{1}$ | $\mathbf{2}$ | $\mathbf{3}$ | $\mathbf{4}$ | $\mathbf{5}$ | Average |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Total Task Time (sec) | 9.34 | 6.46 | 7.24 | 15.42 | 8.02 | 9.23 |
| Total Time Off-Road (sec) | 2.68 | 2.5 | 4.66 | 5.92 | 1.82 | 3.52 |
| Maximum Off-Road Glance (sec) | 0.58 | 1.3 | 1.32 | 1.1 | 0.58 | 0.98 |
| Total Number Off-Road Glances | 7 | 3 | 4 | 10 | 4 | 5.6 |
| Avg 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 |
| Avg On-Road Glance | 0.42 | 0.56 | 0.24 | 0.52 | 1.03 | 0.55 |

Table 2.4 Summary of glances for five subjects looking at the odometer (s)

Other interesting statistics can be computed for the length of individual glances during the different tasks. Figures (2.5-2.6) illustrate the difference in glance lengths to and from the roadway for each of the three glance oriented tasks. Different pair-wise comparisons have been completed between the mean positions during various tasks using t-tests (with $\alpha=0.05$ ). Similarly the f-distribution has been used to compare the standard deviations of different groups of eye positions. The average on road glance time for the radio task is 0.52 seconds and the time of an average on road glance for the rear view task 0.55 seconds. These average glance times have been compared pair-wise to show that they are significantly less than the off road glance times with $(p<0.05)$. When a similar comparison is completed for the off and on road glance times for the odometer, the difference is not significantly significant. A
pair-wise comparison between the off road glance times for the radio and rear view mirror also shows no significance.


Figure 2.5 The total number of on-road glances of various length during the three glance tasks.


Figure 2.6 The total number of off-road glances of various length during the three glance tasks.

It is also possible to consider the differences in movement times that occur during the glance task as displayed in Figure 2.7. These average movement times are not significantly different for the three tasks, suggesting that driver's movement and search times do not vary based upon the task being completed. It is interesting to note that the percentages of movements in each bin remains relatively constant regardless of the task type.


Figure 2.7 The total number of movements of various length during the three glance tasks.

The second type of distraction, cognitive distraction, can be analyzed the scanning that occurs while the driver is in thought as illustrated in Figure 2.4. For these types of distractions it is better to consider the average horizontal, and vertical position of the eye as well as the standard deviation for the horizontal and vertical positions. These measures have been summarized for a fixed group of five drivers with the total task time in Table ( $2.5-2.6$ ) for the first and second cognitive tasks respectively. A comparison can then be made to the means and standard deviations computed from a control. The control computed from the entire data record without the instructions and task times, is summarized in Table 2.7. To determine if significant differences exist in a driver's eye movements during the completion of different cognitive tasks, the subjects chosen were kept constant through this analysis.

| Measure | $\mathbf{1}$ | $\mathbf{2}$ | $\mathbf{3}$ | $\mathbf{4}$ | $\mathbf{5}$ | 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 |
| Std. Dev. Horizontal Positions | 26.32 | 29.12 | 35.39 | 70.79 | 39.51 | 40.23 |
| Std. Dev. Vertical Positions | 8.59 | 8.52 | 16.04 | 26.03 | 11.65 | 14.17 |

Table 2.5 Eye movement summary for the first cognitive task (s)

| Measure | 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 <br> Positions | 37.70 | 47.81 | 50.20 | 68.28 | 43.75 | 49.55 |
| Standard Deviation Vertical <br> Positions | 10.04 | 15.52 | 10.30 | 20.71 | 21.55 | 15.63 |

Table 2.6 Eye movement summary for the second cognitive task (s)

| Measure | $\mathbf{1}$ | $\mathbf{2}$ | $\mathbf{3}$ | $\mathbf{4}$ | $\mathbf{5}$ | 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 <br> Positions | 89.20 | 82.18 | 89.96 | 97.92 | 88.72 | 89.59 |
| Standard Deviation Vertical <br> Positions | 28.56 | 22.43 | 28.43 | 27.93 | 26.54 | 26.77 |

Table 2.7 Control summary for the entire drive excluding task completion (s)

To identify differences that exist between the eye positions recorded during the test periods and the controls, four statistics have been computed. First, the mean horizontal and vertical positions of the first cognitive task are compared with the controls pair-wise over all five subjects. Both comparisons show that there is a significant difference between the horizontal and vertical movements during the cognitive task and the control ( $p<0.05$ ). Second, the standard deviations of the recorded eye positions have been compared. As in the earlier case with the means test, two comparisons are completed. Where the standard deviation of the horizontal movements, and standard deviation of the vertical movements during the tasks have been contrasted with the standard deviations of the control. As in the means comparison, the standard deviations are significantly different with ( $p<0.0001$ ).
A similar analysis can be made for the second cognitive task, while the horizontal movements during the second cognitive task remain significantly different ( $p<0.01$ ),
the mean vertical movements during the task are not $(p=0.36)$. As in the earlier case, the standard deviations of both the horizontal and vertical are significantly different ( $p<0.0001$ ). It is important to consider the differences that exist between the two cognitive tasks. The downward change in vertical eye position, and the increases in the mean standard deviation of horizontal movements is evident the second cognitive task. A statistical comparison confirms these observations, where the shift in the mean vertical position is significantly less in the second task ( $p=0.01$ ), and the horizontal standard deviation significantly greater in the second task ( $p<0.1$ ).

### 2.4 DISCUSSION

This paper demonstrates how various eye movements have been collected and analyzed to compare a driver's performance while performing a variety of in-vehicle tasks. The data collected from this experimentation is consistent with earlier studies. Eye movements for the radio, rear view mirror, and odometer tasks all show the timesharing pattern. Time-sharing results in attention being divided between the primary task of driving and the instructed secondary task. The 1.6 second upper bound on the natural off road glance time of [33] is also observed since only four glances in 208 are noted as being over 1.6 seconds. With such a small sample no safety considerations can be made with these limited results since the reason for the drivers long off the road glances is unknown.
The glance analysis resulted in three significant findings providing some insight into the distraction problem associated with in-vehicle devices. Regardless of the task being completed, the glance times spent on or off-the-road do not vary significantly, while the glance times off-the-road are significantly greater for the radio and rear view mirror tasks but not the odometer reading. 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, while the actual off-road glance times are task specific. Finally, movement times for all tasks also do not show any significant differences. While some interaction between glance type tasks and cognitive tasks is likely to exist since few scanning movements are observed during these tasks, however this was not specifically investigated in this experiment.
While the glance analysis did not find any definitive results, the comparisons formed based upon the two cognitive tasks did. Both the hand held cell phone conversation requiring the calculation and the hands free conversation requiring a memory task showed significant differences from the control. The significant differences found between the means and standard deviations of the first and second cognitive tasks confirms that a driver engaged in some cognitive process reduces the amplitude of their eye movements, and that the much of the reduction is exhibited in a reduced number of movements to the right, and down suggesting that the subject may be following the center line or lead car without monitoring the dash or rear view mirror as often as when not engaged in a cognitive task.
Some differences were found in the vertical positions and horizontal standard deviation of the two cognitive tasks, although no definitive conclusions can be made on the effect of the hand held cell phone or the cognitive task, with such a small sample size. The sample size should have a large effect based on the individual differences of drivers in general. Furthermore, road conditions can also play a role in
a subject's reaction.
The methods developed may be 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 driver's eye movement patterns may be useful tools in detection and classification of driver distraction. Glance analysis may offer metrics for the time taken to complete various in-vehicle tasks, while 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 studding the level of attention devoted to tasks such as manual and hands free cell phone operation, under controlled road situations.

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