Driver Performance on Curves Using a Driving Simulator

A Thesis Presented

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Abstract

We investigated drivers’ behavior and physiological measures while driving on curves with radii of 250 meters. Our investigation included recording eye movements while driving on curves to determine the gaze patterns when making left and right curves. The Galvanic Skin Response (GSR) was recorded to monitor simulator sickness. Measurement of GSR was also used to reveal the physiological reaction to dangerous events. The experiment focused on driving on roads with left and right curves with and without clothoids. Clothoids are the family of spirals whose curvature is linearly related to its curve length. The car’s course consisted of a succession of straight-line and curve sections. We focused on how drivers’ gaze pattern change while driving on left and right curves (with clothoids and without clothoids). Our research was done on a driving simulator with a fixed base in one condition, and in the other condition the simulator had a turning seat, which reflected vehicle heading.

Twelve participants drove approximately 5.5 miles along a curved road environment to complete sixteen curves (eight with clothoid transition, and another eight with normal entry) in about eight minutes. We have the following results:

(1) There was a significant increase in reported Simulation Sickness Questionnaire (SSQ) scores after experiencing the two trials. After run 1, 9 out of 12 subjects had none or the same (slight) value for simulator sickness. Two subjects experienced an increase in nausea. Another two subjects experienced an increase in oculomotor discomfort. One subject experienced a severe increase in general symptoms. After run 2, 8 out of 12 subjects had none or the same (slight) value for simulator sickness. Four subjects experienced a slight increase in nausea. Six subjects experienced an
increase in oculomotor discomfort. One subject experienced slight increase in discomfort.

(2) Subjects took more time to drive on straight sections and on both types of curves when driving static seat simulator as compared to turning seat simulator. 8 out of 12 subjects took more time to drive the static seat simulator than the turning seat simulator for both types of curves.

(3) Subjects took less time to drive on clothoid curves as compared to normal curves in both turning and static seat simulator. This may be due the smooth nature of clothoids as the curvature increases linearly with the arc length.

(4) Fixation of the eye shows that the search patterns for the two types of simulator differ. When driving the static simulator, there was a large difference in the percent of time that they viewed the type of lane marker (center or right edge). However, when the drivers were using the turning simulator, they spent almost the same amount of time glancing at the center lane and right edge markers. The turning seat had a strong effect on drivers search and scan patters when entering curves.

(5) Overall increase in GSR, when the cyclist suddenly appeared in front of the driver, is greater in case of the static seat simulator as compared to that of the turning seat simulator. When using the turning simulator, subjects were physically turning and thus had a higher GSR base value than when driving the static simulator.
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Chapter 1 Introduction

1.1 Background

When we drive, we frequently redirect our gaze - the direction of the visual axis relative to the surroundings - in a way that lets us view the parts of the scene we need to know to drive in a safe manner. Since it is difficult to analyze the driving behavior in a real traffic environment, we have used a driving simulator to measure driving behavior as a part of the project "Driver Performance on Curves Using a Driving Simulator".

There are various advantages of using driving simulator for measuring driving behavior because we can control the traffic situations like behavior of other vehicles, pedestrians (Akamatsu et al., 2001). He also mentioned that not only can we control the traffic situations but also record the drivers’ behavioral measures. This may not be possible while driving on the real roads. Although, there is so much potential for the use of virtual reality environments in clinical rehabilitation, some applications are limited in this field due to their problems (Riva, 2001). Some people may experience side effects when exposed to virtual reality environments. Symptoms like nausea, ocular discomfort, disorientation and general discomfort are experienced by some users. Turning-cabin driving simulator improves the driving feeling and makes the driver’s sight behavior very close to that in case of real world driving (Asano & Uchida, 2005).

Clothoids (or Cornu spirals) are very useful curves known to smooth trajectories. Clothoids allow us to link curves of infinite radius of curvature (i.e., lines) and curves
of finite radius of curvature, with a continuous change of the curvature. Clothoids have practical applications in railway and highway design. Clothoids are very useful to smooth the motion of a mobile robot that is moving along a trajectory (Fleury et al., 1995). Our study will investigate the use of clothoids to smooth the motions of a car when driving on the curves (i.e., when the driver changes the direction of vehicle motion).

1.2 Overview

The goal of this thesis is to investigate driver performance while driving on left and right curves in a fixed base driving simulator and a moving seat simulator. Experiments will record drivers’ eye movements to determine gaze patterns, and record galvanic skin response as an indicator of simulator sickness.

A driver needs to gather visual information from the changing pattern of the road ahead in order to proceed safely (Land & Lee, 1994). We focused on driver’s eye movements while they negotiate a series of curves. Eye movements were recorded to determine their gaze pattern on every curve. When using the term eye movements, it means the fixations of the eye, during which the visual information is picked up.

A driver’s behavior is also affected by geometric road parameters like curvature of the road, number of driving lanes etc. Driving on curves may result in an increase in heart rate, and dangerous situations may result in an increase in GSR. We recorded various physiological measures (heart rate and galvanic skin response) to determine the behavior of a driver while driving the simulator.
Our driving environment is a succession of straight-line and curve sections. We focused on how drivers execute various left and right curves. There were two types of curves, clothoid curves and normal curves (curves of constant curvature).

1.3 Literature Review

Various studies have been conducted on driving in the virtual simulated environment, tracking eye movements and driver’s behavior while driving on the curves. It should be noted that patterns of eye movements vary from person to person. Driver’s eye movements exhibit different patterns of fixation behavior for different driving tasks such as lane keeping (Mourant & Rockwell, 1970). It is actually possible to know the future actions or behavior of the driver in advance, since the gaze is ahead of the motion of the car, although by very few seconds. For example, our brain realizes to apply brakes when we see a pedestrian. The following literature reviews report the results of previous studies.

In a research study by Cohen and Studach (1977), it was found that for experienced drivers in a curve to the left, the mean duration of eye fixations was longer and the amplitude of the eye movements greater than in a curve to the right. They did not observe such difference in inexperienced drivers who manifested neither uniformity within the same curves nor differentiation between the two types of curves. Their results show that the mean duration of eye fixations of experienced subjects was shorter while driving in a curve to right, but the amplitude of eye movement was greater in a curve to left than those of inexperienced drivers. It was also pointed out that there was a change in the pattern of eye movements prior to entering a curve.
Also, upon approaching the curve the mean duration of eye fixation decreased, and the fixations were mainly shifted toward the future-driving path.

Land and Lee (1994) in their article on “where we look when we steer” mention “Steering a car requires visual information from the changing pattern of the road ahead”. They recorded the steering-wheel angle and drivers’ gaze direction simultaneously during a series of drives along a tortuous road. It was found that drivers relied particularly on the 'tangent point' on the inside of each curve, seeking this point 1-2 sec before each bend and returning to it throughout the bend. Their results also show that the curvature of the road could be predicted by taking the direction of this point relative to the car's heading.

According to an IEEE paper by Land, M.F. (1993), eye and head movements at intersections are closely related and can be predicted accurately by the size and timing of each gaze change. They mentioned that while driving on the curve, each phase has different gaze movement associated with it. It is also mentioned that “during the approach the eyes typically seek out clues to the curve's curvature; during the curve, they are directed into the curve, and away from the car's heading; and during the exit, gaze is held on targets beyond the bend, with the car and body counter-rotating beneath the head”.

“Drivers fix their gaze where they are planning to go” (Giannopulu et. al, 2007). Giannopulu et. al (2007) considered that steering is based on optic flow. They compared the visuomotor strategies in various virtual and pre-recorded environments in a fixed-base driving simulator. To study this, experienced car drivers were exposed
to two visual environments: a real traffic urban scenario pre-recorded on video and the 3D simulation of the same scene. Subjects’ visual strategies were recorded using a binocular eye tracking system (Eyelink II). They supposed that visuomotor strategies depend on the similarities between both the environments. The results indicated that there is a difference in the eye movements between the two types of environment - pre-recorded and virtual environments. They mention that these results can be explained by the integration of information in the saccade buffer and visual attention control.

Another study tested that the drivers turning right simply focus their attention on the cars coming from the left assuming that there is no threat from the cars coming from the right and so they fail to see the cyclist from the right early enough (Summala et al., 1996). In this study, drivers' scanning behavior was studied at two T-intersections using two well-hidden video cameras - one to measure the head movements of the approaching drivers and the other to measure speed and distance from the cycle crossroad. The results supported the hypothesis “drivers, while taking a right turn, scan the right leg of the T-intersection less frequently and later than those turning left”. It was also noted that drivers develop a visual scanning strategy, they concentrate on more frequent and major dangers, and completely ignore the less frequent dangers. They also studied the drivers' visual search behavior with respect to the countermeasures, including speed humps. The result of this part of the study suggests that speed-reducing countermeasures changed drivers' visual search patterns in favor of the cyclists coming from the right as they get more time to focus in each direction.
Hayami et al. (2002), to detect drowsiness while driving, compared the eye closure rate with the vertical eye movement frequency between wakeful and drowsy states of drivers using a driving simulator. It was found that frequency values were high for both the measures in the drowsy state condition, and were significant enough to distinguish between the two states with a threshold. They defined the threshold level, which was used to distinguish the two states, as the rate at the cross point of the curves of two possibility density functions made by the frequency of the rates of the two measures at the two states.

Falkmer & Gregersen (2005) compared the eye movement behavior of inexperienced and experienced drivers in real traffic environments. The hypothesis of their experiment was that “inexperienced drivers, in comparison to experienced drivers, fixate closer to the vehicle, fixate more often on in-vehicle objects, spread their fixations less along the horizontal meridian, fixate more often on relevant traffic cues, and fixate more often on objects classified as potential hazards”. They analyzed the data from eye-tracker recordings of visual search strategies of the driver in real-world traffic. The results confirmed all stated hypotheses regarding differences between inexperienced and experienced drivers. The only ambiguous result was in case of fixation closer to the vehicle.

A study on vision, visibility, and perception in driving confirmed that errors of perception by the driver are a major contributory factor to accidents (Hills, 1980). He mentioned that for all drivers, the rapid fall in visual acuity with angular distance from the center of vision is one of the reasons of problems. Other problems may include eye-movement patterns and the problems of visual search. He said that
numerous physical and psychophysical restrictions on visibility could lead to the "looked, but failed to see" type of accident, but their relative importance requires evaluation. The study concluded that expectations based on experience, in both the long and the short term, influence the driver’s perception and assessment of risk. He also mentioned that serious errors of judgment from time to time seem evitable for all drivers.

Borowsky et al. (2008), in their research study, determined how driving experience and expectations affect the ability of experienced drivers to identify traffic signs—specifically, no right turn (NRT) and no left turn (NLT) at intersections. To study this, inexperienced and experienced drivers were connected to an eye tracker system and were briefly exposed to various traffic scenes. Scenario consisted of expected and unexpected signs. It included an NRT sign at the expected location (on the right), and also the same sign at an unexpected location (on the left). The same procedure was used with an NLT traffic sign. It was found that experienced drivers identified traffic signs better than inexperienced drivers when the signs were posted at the expected location. They were worse than inexperienced drivers when the signs were at unexpected locations. It was concluded that experienced drivers’ expectations regarding the expected location of traffic signs become so strong that they make more errors than inexperienced drivers when these expectancies are violated. The study suggests that highways must be designed so that they must conform to the standards of experienced drivers’ expectations.

Kito et al., in 1989, did another study on measurement of eye movements while driving. Gaze movements of drivers in large vehicles were compared with those in
small vehicles. Their results show that there were both similarities and differences in the visual search behaviors of drivers of large and small vehicles. The similarity was that, drivers made repeated saccadic gaze movements when approaching an intersection; and saccadic gaze movements were directed ahead in the direction of turning after entering the intersection. The difference was in the frequency and distribution of gaze movements. The number of gaze movements was significantly greater in drivers of large vehicles.

Optic flow is generated as a user’s vehicle traverses a three-dimensional virtual environment (Mourant et al., 2007). The paper mentions that amount of optic flow is greatest directly in front and to the sides of the vehicle, with optic flow being zero at the point of expansion. In the experiment, the method of paired-comparisons was used to investigate perceived optic flow for different sizes of geometric field of view (GFOV). Results established that subjects could accurately differentiate the amount of optic flow for the different levels of GFOV. In addition, subjects perceived the velocity of on-coming vehicles to be faster when the GFOV was large.
Chapter 2 Clothoids

In Chapter 1, a comparison was drawn between curves with clothoids and normal curves. This chapter gives a brief description of Clothoids.

2.1 What is a Clothoid?

A clothoid or cornu’s spiral, as described by Euler (1774), is a curve whose curvature is proportional to the length of the curve measured from the origin of the spiral. They are also known as Euler curves. They are preferred for a path that consists of straight lines and circles and the curve is discontinuous (Modern differential geometry of curves and surfaces with Mathematica By Alfred Gray). Figure 1 below shows a Spiral clothoid curve whose curvature begins at 0.

Figure 1. Spiral Clothoid Curve (Wikipedia, 2008)
2.2 Equation

The Fresnel integrals as invented by Augustin Jean Fresnel are given by the following equations:

\[
C(t) = \int_0^t \cos \left( \frac{\pi}{2} u^2 \right) du,
\]

\[
S(t) = \int_0^t \sin \left( \frac{\pi}{2} u^2 \right) du,
\]

Where \( u \) is a non-negative parameter.

Clothoids can be derived using Fresnel integrals as presented by Heald (1985):

\[
C(t) \approx \frac{1}{2} R(t) \sin \left( \frac{1}{2} \pi (A(t) - t^2) \right)
\]

\[
S(t) \approx \frac{1}{2} R(t) \cos \left( \frac{1}{2} \pi (A(t) - t^2) \right)
\]

Where

\[
R(t) = \frac{0.506t + 1}{1.79t^2 + 2.054t + \sqrt{2}}
\]

\[
A(t) = \frac{1}{0.803t^3 + 1.886t^2 + 2.524t + 2}
\]

2.3 A Related Study on Clothoid Curves

A Eurographics Workshop paper on Sketching Piecewise Clothoid Curves (McCrae & Singh, 2008) discussed a new approach to “sketching 2D curves with varying curvature as piecewise clothoids”. According to this research paper, it is required to
denoise and process the polyline stroke data into fair 2D curves in order to use it further in sketch-based applications. It is also mentioned that iterative smoothing is the best-suited way to remove high frequency sketching noise. McCrae & Singh’s approach to process sketch strokes is a two-step process, which is described as “First, fit a piecewise linear approximation to the discrete curvature of the stroke as a function of arc-length, with control over the tradeoff between fitting error and the number of linear pieces. The next step involves determining a single 2D rigid transform that aligns this composite curve with the sketched stroke to minimize the error of the stroke from the transformed curve (McCrae & Singh, 2008)”

2.4 Our Approach

Figure 2 below shows a bird’s eye view of a curve with a clothoid. The direction of travel is from the lower edge of the road to the upper edge.

![Figure 2. Curve with clothoid.](image)
The goal of clothoid use is to yield a smooth transition of curves. Using clothoids to design curves has many advantages as curvature radii change regularly along the path. Code for implementing clothoid curves is presented in Appendix C and was based on the work of McCrae and Singh (2008). To design a clothoid curve the following values are needed: starting point, width of the road, image file name (that is to be used as a texture), and number of segments.
Chapter 3 3D Environment

3.1 Basic Components of the Environment:

Basic components of the 3-D environment include roads, signs, trees, autonomous vehicles, buildings, 3-D models of houses, and a bicyclist.

3.1.1 Roads

The 3D environment that was created as a part of this thesis is a sequence of straight and curved paths. There are two types of curves created as a part of this thesis, clothoid and normal curves. Curves with clothoids have been described in the previous section. Figure 3 below shows the bird’s eye view of a normal curve.

Figure 3. Bird's eye view of a normal curve.
Design of Straight Sections

Figure 4 shows the straight road section.

![Straight Road](image)

Figure 4. Straight Road.

Code for designing this is in Appendix C. The values that are needed to design a road are start point (ps), end point (pe), width of the road to be drawn (w), image filename that is to be used to draw the road segment (imageFileName) and the number of tiles for which the road should be drawn (numTiles).
Design of Curved Sections

Figure 5 below shows the screenshot of the environment while entering a normal right curve.

Figure 5. Normal Right Curve.

Figure 6 below shows the screenshot of the environment while entering a normal left curve.

Figure 6. Normal Left Curve.
Figure 7 below shows the screenshot of the environment while entering a clothoid right curve.

![Figure 7. Clothoid Right Curve.](image)

Figure 8 below shows the screenshot of the environment while entering a clothoid left curve.

![Figure 8. Clothoid Left Curve.](image)
There were 16 curves in the complete scenario. Out of which, 8 were with clothoid and the other 8 were without clothoid. As can be seen from the screenshots, the curvature for the clothoid curves seems to be changing slowly and smoothly. Code for implementing normal curves is in Appendix C. The values that are needed to design a normal curve are start point (ps), end point (pe), point through which the curve passes (pc), width of the road to be drawn (w), image filename that is to be used as a texture of the road segment (imageFileName) and the number of tiles for which the road should be drawn (numTiles).

3.1.2 Signs and trees

These elements are necessary for the creation of a realistic driving environment. It is required to design environments that are photorealistic which can be done using high quality models of trees, bushes, buildings, sidewalks, signs, traffic lights etc.

Another common approach is to use an artistic metaphor for scene design (Raggett, 1994). An artist, unlike a photographer, chooses which elements to capture in order to create a sense of the environment. It is required to add the elements, which give a realistic look, in addition to the ones, which are necessary to design the scenario. Two such scenery design aspects discussed here are signage and foliage.

Signs play important role in virtual environments. They are required as they provide necessary information to the driver for navigating the environment. Also, they give a realistic look to the environment. A designer friendly signage system has been implemented in this thesis. The vegetation is varied as in real world thus creating a real virtual driving environment.
Figure 9 shows a speed limit sign and trees used in this thesis.

![Figure 9. Signs and trees in the environment.](image)

### 3.1.3 Autonomous Vehicles

Autonomous vehicles are one of the most encountered elements in a driving simulator. They have critical impact on the look and feel of the virtual environment.

In this thesis moving autonomous entities are used. The models were created using Milkshape 3d. The autonomous vehicles are triggered to begin moving when the user driven vehicle intersect a non visible “software trigger” in the virtual environment. Figure 10 show oncoming vehicles in a scenario.
For a vehicle the values needed are the vehicle index, scaling factor, rotation angle, orientation, location, speed, and lane index. Code for vehicles is in Appendix C.

3.1.4 Buildings

Buildings are added to the road network as the virtual environment is built. The position and type of the buildings to be placed are determined for each section of the road. Each building is scaled to the required size and shape, and is placed at the required location. Building must be designed keeping in mind the type of area where they are being placed, that is, rural or urban. Figure 11 shows the buildings in the environment designed for this thesis.
The data for the buildings are read by the load function of Buildings.cpp. For the building the values needed are the position, scaling factor, rotation and the texture of the front, side, and roof. Code for designing buildings is in Appendix C.

3.2 Generation of the 3D Environment

The 3D environment has been generated and implemented by selecting appropriate roads, road map, signs, foliage, buildings, traffic and pedestrians. The environment consists of a sequence of straight and curved paths. Each section of the road is populated based on the requirement in that area. For example, a school zone must have traffic lights with proper speed limit signs and school start and end zone signs. To generate an environment, first it is determined what kind of area it is (rural or urban). The next step is to set the road map and populate the environment with appropriate elements like building, trees, traffic lights and signs. Then the traffic (autonomous vehicles) is added based on the requirement. For example, it can be a
downtown with a lot of traffic or a suburb with minimal traffic. In this study, road
signs have been placed at the start of each of the straight sections and that of the
curved sections.
Chapter 4 System Description

4.1 Hardware Description

Following is the description of the hardware that was used for our study.

4.1.1 Driving Simulator

Figure 12 shows the driving simulator in the Virtual Environments Laboratory at Northeastern University where the experiment was conducted.

![Driving Simulator](image12.jpg)

Figure 12. Driving simulator in the Virtual Environments Laboratory.

The driving console has a racing seat, steering, gas and brake pedals and a speedometer. The racing seat is mounted on an AC servo actuator at the center of the cylindrical screen. The force feedback steering wheel, gas and brake pedals are attached to the seat. It has 360 degrees of rotation.
4.1.2 Macintosh Computer and Projectors

The simulation was rendered using a Macintosh Computer (2*2.8 GHz Quad core Intel Xeon processor, 4GB RAM, 512 MB VRAM NVidia GeForce 8800 GT graphics card). The video output was connected to 3 LCD projectors, which projected the view onto a curved screen, which is 11 feet in height and 12 feet in diameter. The output was projected at a resolution of 3072 x 1024 pixels, which gave a 180 degrees horizontal field of view. The frame rate was approximately 100 frames per second.

The computer also included a sound card, which generated sounds from pre-recorded sound samples loaded on its onboard memory. Good quality sound speakers were used to emulate the acoustic environment in terms of road and wind noise.

4.1.3 ASL Eye Movement Camera

Eye movements were recorded using a Windows computer (Windows XP, 2 GHz core duo Intel processor, 1GB RAM). The computer was connected to a Spectacle Mounted Unit (SMU) through a Recordable Mounted Unit (RMU).

The SMU (shown in Figure 13) contains the scene camera, the eye camera, and a short distance audio microphone. The SMU was mounted onto goggles and was connected to the RMU. The IR Illuminator was located in the eye camera housing.
The RMU (shown in Figure 14) was used to record and play video in the field, and interfaces with analysis computer.
4.1.4 Psychometric Research GSR Meter

The Psychometric Research GSR Meter is a professional biofeedback monitor designed for hypnotherapy and psychotherapy (source: Psychometric Research). It comes with comfortable and unobtrusive velcro finger straps with high-conductivity copper electrodes. Galvanic skin response (GSR) was measured by attaching two straps to the skin, and acquiring a base measure. Figure 15 below shows the GSR meter.

![GSR Meter](image1)

Figure 15. GSR Meter. (source: Psychometric Research)

Figure 16 below shows the way of attaching the GSR sensor to the fingers.

![Velcro Straps Attached to Fingers](image2)

Figure 16. Velcro straps attached to fingers. (source: Psychometric Research)
4.2 Software Description

Virtual environments provide an affordable and consistent way to expose a user to a scenario. To minimize the cost of the simulation and maximize its efficiency we worked on technologies which are open source and with which we can have maximum possible control of the application in terms of performance and optimizations. Hence we used the C/C++ programming languages to do the coding for the virtual environment with OpenGL and SDL (Simple DirectMedia Layer).

4.2.1 OpenGL

The OpenGL API (Application Programming Interface) began as an initiative by SGI to create a single, vendor-independent API for the development of 2D and 3D graphics applications. Prior to the introduction of OpenGL, many hardware vendors had different graphics libraries. This situation made it expensive for software developers to support versions of their applications on multiple hardware platforms, and it made porting of applications from one hardware platform to another very time-consuming and difficult. The OpenGL API began as a specification, and then SGI produced a sample implementation that hardware vendors could use to develop OpenGL drivers for their hardware. Programming using OpenGL is primarily done in C/C++ but can be done with various other programming languages (Source: SGI – Products: Software: OpenGl, 2009).

4.2.2 SDL

Simple DirectMedia Layer (SDL) is a cross-platform multimedia library designed to provide low level access to audio, keyboard, mouse, joystick, 3D hardware via
OpenGL, and a 2D video framebuffer. It is used by MPEG playback software, emulators, and many popular games, including the award winning Linux port of "Civilization: Call To Power". Simple DirectMedia Layer supports Linux, Windows, BeOS, MacOS Classic, MacOS X, FreeBSD, OpenBSD, BSD/OS, Solaris, IRIX, and QNX. SDL is also an open source product and is available under the GPL license (source: Simple DirectMedia Layer).

An image editor was required for the purpose of designing quality textures, which were used in the virtual environment. We chose Gimp since it is open source software and is very powerful. The autonomous vehicles used in the simulation are MilkShape 3d models. Using ms3d (MilkShape) models has the following advantages:

1. Very good support with SDL and OpenGL.
2. Milkshape3D modeling software is a shareware and the full license is available for a very nominal price.

### 4.2.3 CAD Software:

CAD software was needed to input points in the data files to design a scenario. We used AutoCAD for this purpose, as it is the industry standard and was easy to work with. AutoCAD is an interactive drawing system that allows a user to design or edit a graphics drawing on the display screen. It provides a graphics developer a platform to draw the roads, position buildings, signs, trees etc and define the path of traffic and scenario objects.
4.2.4 JaxCam

JaxCam Web Monitoring software is a powerful multiple-channel video surveillance system. JaxCam allows managing almost unlimited cameras at once by receiving and encoding the video feeds in real-time. JaxCam can be configured to detect motion in a specific monitored area, use scheduler to set-up specific time for monitoring, enable the stealth mode, send off alarm alerts, and upload captured video in an array of methods such as email and FTP (source: JaxCam Video Surveillance Solutions). It helped us archive, manage, and browse recorded video within the same program. We used Jaxcam to record and manage two cameras, one mounted to record the GSR, and the other mounted behind the steering to record the facial expressions of the driver.

4.2.5 EyeVision

The ASL eye movement camera required calibration for each subject. The software, Eyevision, was used for this purpose. It was preinstalled on the ASL computer. The video contrast level of the eye image needed to be adjusted so that the boundary between the pupil and the iris was well defined.
Chapter 5 Methodology

5.1 Participants

Participants of the experiment were recruited from students enrolled at Northeastern University. Participants were between the ages of 20 and 25 with an average age of 22.9 years. Twelve subjects participated in the experiment. They were required to have a valid driver’s license and have driven at least 5000 miles in the United States during the past 12 months. All subjects had corrected vision of 20/30 or better. Students who wear soft lenses could be recruited for the experiment, but we couldn’t recruit students with glasses or hard lenses, as they do not work with the apparatus for recording the eye movements.

5.2 Procedure

Subjects were asked to sign a consent document, fill out a background form, and a Simulator Sickness Questionnaire (SSQ). After filling the forms, the subject was asked to get into the simulator. Now, the experimenter read the following instructions to the subject before starting the simulator familiarization run:

✓ Please be seated in the vehicle and adjust the seat (forward / backward) so that you can comfortably operate the gas and brake pedals.
✓ Please calibrate the steering by turning the steering all the way to the left and then all the way to the right.
✓ Place your hands on the steering wheel and when I tell you to start, press on the gas pedal to proceed.
Please follow all the signs and signals.

If at any time you do not feel well you may stop, and I will turn off the simulator.

Subjects were then given a trial run to get familiar with the driving environment.

Then a sensor to measure the galvanic response was attached to the subject. The eye movement camera was mounted and calibrated for each subject. Calibration of the eye movement camera involved a number of steps and took less than 10 minutes for each subject.

There were two variations of the simulator- static seat and turning seat. Each subject was asked to drive the simulator for the two conditions.

They were given instructions to drive normally, obey all the traffic signs and signals, and drive at the assigned speed limit. Subjects were asked to drive in the centre of the right lane. Subjects could see their speed on the dashboard-mounted speedometer, and were asked to drive at a speed as per the posted speed limits. Participants filled out the SSQ after the first run (16 curves) and had a break for 5 minutes before they were given the second run (another 16 curves). This break was intended to diminish as much as possible the possible fatigue effect. At the completion of the second run, participants again filled out the SSQ, and a post data collection form. Each subject was paid an honorarium of $20 for participation in the experiment.

It took about 45 minutes to complete the experiment for each subject.
5.3 Setting up the Eye Movement Camera:

Calibration involved the following steps to be done on the analysis computer. These steps are as explained in the CD that came along with the ASL camera.

5.3.1 Start EyeVision

Selecting the EyeVision icon on the Analysis Computer desktop brings up the EyeVision program with the video display of the eye (fed from the DVCR) on the left and the control panel on the right. Subject profile is required to be changed for each subject.

The Subject Profile section of the control panel shows which user file is currently loaded (Figure 17 shows directory C:\Program Files\ASL Mobile Eye\ which is the subject profile).

Figure 17. Eye vision software. (Courtesy: ASL).
5.3.2 Establish the data file name

Create a new user profile using “Load” and then Save it.

5.3.3 Set up the eye and scene images

It was needed to calibrate the system prior to the task to ensure a good calibration before any activity is started. You must position the image of the eye within the Display Window. Select Display under the Alignment heading to bring up the raw eye image, and then adjust the mirror on the eye tracker.

5.3.4 Attune the spot (CR) image

The video contrast level of the eye image needs to be adjusted so that the three corneal reflections are clearly visible and their relative positions need to be defined. This is done using the controls under the Spot heading. This will place a black box binary map over the area of the eye image that EyeVision is searching for the spot cluster. The spot cluster will be recognized if the Master spot and at least one other spot is visible. If the system does not recognize the spot cluster, it will not be able to track eye gaze. Figure 18 shows the spot display during calibration.

Figure 18. Spot display during calibration. (Courtesy: ASL)
5.3.5 Adjust the pupil image

The video contrast level of the eye image needs to be adjusted so that the boundary between the pupil and the iris is well defined. When the pupil is recognized, it will be marked with a yellow circle. The Score in the top left corner of the Eye Display is a measure of the reliability of the calculated pupil position. If it drops below a set limit, the pupil position for that frame is discarded. Figure 19 shows the pupil display with overlay.

![Pupil display with overlay and pupil score.](image)

Figure 19. Pupil display with overlay and pupil score. (Courtesy: ASL)

5.3.6 Calibrate the scene image

The Scene Calibration function maps eye movement against scene data by relating the positions of eye features (the pupil and CR cluster) to known positions within the scene image. It uses the controls in the Scene section.
5.3.7 View / Record data stream from DVCR

Once the system is set up and calibrated, EyeVision analyses the eye image and calculates gaze direction relative to the corresponding field of scene data. Interleaved eye and scene data can be input to the system either in real time (direct mode) or from a videotape (recording mode). The gaze direction is output as a Point of Gaze marker superimposed on the scene video image and, using the DataLog facility, as an ASCII format (.csv) data file.
Chapter 6 Data Analysis

6.1 Scoring Guideline

Each subject was evaluated based on 1) responses to the Pre-Exposure SSQ ( Simulator Sickness Questionnaire) and the Post-Exposure SSQ (after Run 1 and after Run 2), 2) responses to a questionnaire after each experimental run, 3) eye fixation times and 4) galvanic skin responses. Guidelines for arriving at scores are explained below.

6.1.1 Simulator Sickness Questionnaire Guidelines

The Pre-Exposure SSQ and Post-Exposure SSQ contain the same set of questions. The subject filled the SSQ (Kennedy et al., 1993) before and after getting into the simulator respectively. The SSQ has 26 symptoms and provides scores in 4 categories. The categories are

✓ Nausea
✓ General Factors
✓ Ocular Discomfort
✓ Disorientation

To Find the SSQ score, participants are asked to report the degree to which they experience the symptoms in each of the above category as “None”, “Slight”, “Moderate” and “Severe” which are scored respectively as 0 to 3. They can then be multiplied by the weight in each column and added to obtain the total SSQ Score. (Prothero, 1998)
6.1.2 System Questionnaire

At the end of each experimental run, the subject was asked a set of 5 questions. The answer was recorded on a scale of 1 to 7 where 1 is rated as poor and 7 as excellent. The total of all the responses for each run can be used to compare the performance on the static and turning simulator. Hence adding the values of responses corresponding to each category would provide the final questionnaire score value.

6.1.3 Eye Glance Times

Eye glance time was calculated from the videos recorded using the ASL eye movement camera. An eye glance was defined as the sum of a sequence of eye fixations within one visual degree of a target. Videos were analyzed frame by frame so as to find the time of eye glances on various elements of the environment while driving on the curves. The various elements of the environment are listed as below:

- On the center lane marker
- On the right edge of the road
- Sign
- Tree
- Sky
- Traffic
- Buildings
- Unknown

Total time in each category is the sum of the various eye glance times on that element while driving on the curves. The category Unknown refers to the time period when
the eye movement could not be tracked. It may due to an eye blink or eye movement in the area that was out the focus area of the eye movement camera. Figure 20 is the screenshot from the video that has the eye movements. The red circle shows the gaze at any moment of time.

![Figure 20. Eye fixation location is the center of the red circle.](image)

### 6.1.4 Galvanic Skin Response

To determine the change in GSR with the occurrence of any dangerous event, a cyclist was added to the scenario to appear suddenly in front of the driver while driving on the final straight path.

GSR value was measured over the period of 30 seconds before the cyclist appeared. This mean value over this range of time was taken as a base measure. Then, as the cyclist came in front of the driver there was an increase in GSR, which was noted down as an increased value. The difference between the two values was analyzed.
Figure 21 is the screenshot of the Jaxcam software that recorded the video of the camera placed facing the GSR meter and the other camera facing the subject’s head to record the facial expressions.

Figure 21. Jaxcam recording to measure GSR and head movements.
6.2 Statistical analysis:

6.2.1 Analysis of Simulator Sickness Questionnaire (SSQ)

Each subject was asked to fill out a Pre-Exposure (SSQ) before starting the experiment. This questionnaire is in Appendix A. The subject was also asked to fill out a Post-Exposure (SSQ) after Run 1 (16 curves) and another (SSQ) after Run 2 (another 16 curves). This way, any sickness before and after exposure to the driving simulator runs could be compared.

The set of symptoms in the SSQ are broken down into 4 categories, which are nausea, general discomfort, disorientation and ocular discomfort (Kennedy et al., 1993). The SSQ questions pertinent to each category are shown in Table 1 below.

<table>
<thead>
<tr>
<th>SSQ Symptom</th>
<th>Nausea</th>
<th>Oculomotor</th>
<th>Disorientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>General discomfort</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Fatigue</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Headache</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Eyestrain</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Difficulty focusing</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Increased salivation</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sweating</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Nausea</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Difficulty concentrating</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Fullness of head</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Blurred vision</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Dizzy (eyes open)</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Dizzy (eyes closed)</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Vertigo</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Stomach awareness</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Burping</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 2 shows the pre-imposed SSQ score for run 1. It compares SSQ score for the symptoms that were seen before the start of the experiment, after first run and then after the second run.

<table>
<thead>
<tr>
<th>Subject No:</th>
<th>Nausea Before Run 1</th>
<th>Oculomotor Discomfort Before Run 1</th>
<th>Disorientation Before Run 1</th>
<th>General Factors Before Run 1</th>
<th>Nausea After Run 1</th>
<th>Oculomotor Discomfort After Run 1</th>
<th>Disorientation After Run 1</th>
<th>General Factors After Run 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>0</td>
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<tr>
<td>3</td>
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<td>4</td>
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<td>0</td>
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<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
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<tr>
<td>8</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>3</td>
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<td>3</td>
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<tr>
<td>9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>10</td>
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<td>0</td>
<td>0</td>
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</tr>
<tr>
<td>11</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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</tr>
<tr>
<td>12</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

After run 1, 9 out of 12 subjects had none or the same (slight) value for simulator sickness. One subject experienced a moderate and another subject a severe increase in nausea. One subject experienced a slight and another subject a severe increase in oculomotor discomfort. One subject experienced a severe increase in general symptoms. The twelfth subject reported not feeling well and so experienced severe nausea, oculomotor discomfort and severe general discomfort. He was given a break of 10 minutes between Run 1 and Run 2 for these factors to dissipate.
Table 3 shows the SSQ scores after the first run and after the second run.

<table>
<thead>
<tr>
<th>Subject No:</th>
<th>Nausea</th>
<th>Oculomotor Discomfort</th>
<th>Disorientation</th>
<th>General Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>After Run 1</td>
<td>After Run 2</td>
<td>After Run 1</td>
<td>After Run 2</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
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<td>6</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>4</td>
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<td>1</td>
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<tr>
<td>12</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

After run 2, 8 out of 12 subjects had none or the same (slight) value for simulator sickness. Four subjects experienced a slight increase in nausea. Five subjects experienced a slight increase in oculomotor discomfort. One subject experienced slight increase in discomfort. One subject reported severe increase in oculomotor discomfort.

Table 4 shows the Mean SSQ Scores: 1) before data collection, 2) after the first run of driving 16 curves using the static simulator, and 3) after the second run of driving 16 curves on the turning seat simulator. From the data it is clear that there is a higher Mean SSQ Score for post exposure than for pre exposure, which has further increased after the second run. However, these increases can be attributed to only two subjects and thus are not statistically significant.
Table 4
Mean SSQ Score Vs Exposure

<table>
<thead>
<tr>
<th></th>
<th>Mean SSQ Score</th>
<th>S.D SSQ Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Exposure</td>
<td>0.89</td>
<td>1.46</td>
</tr>
<tr>
<td>Post-Exposure (After 1st run)</td>
<td>1.49</td>
<td>2.29</td>
</tr>
<tr>
<td>Post-Exposure (After 2nd run)</td>
<td>2.62</td>
<td>2.78</td>
</tr>
</tbody>
</table>

Figure 22 and Figure 23 are graphical representations of the data in Table 4 for mean and standard deviation values respectively.

Figure 22. Mean SSQ Scores before and after Simulator trials
Figure 23. Standard Deviation of SSQ scores before and after simulator trials.

The three subscales of the SSQ were computed by summing the scores for the component items of each subscale and multiplying by an appropriate weighing factor (9.54 for Nausea, 7.58 for Oculomotor, and 13.92 for Disorientation) (Prothero, 1998). The total SSQ score was equal to the sum of the three subscales multiplied by 3.7. The mean and standard deviation can be calculated from the total value for each subject.

6.2.1.1 Analysis of SSQ Scores by Category

The SSQ is divided into 4 subscales - 1) Nausea (General discomfort, increased salivation, sweating, nausea, difficulty concentrating, stomach awareness, burping), 2) Oculomotor Discomfort (general discomfort, fatigue, headache, eye strain, difficulty focusing, difficulty concentrating, blurred vision), 3) Disorientation (difficulty...
focusing, nausea, head fullness, blurred vision, dizzy: eyes open, dizzy: eyes closed, vertigo), and 4) General Factors.

Tables 5 contain the Mean SSQ scores and standard deviations for each category.

<table>
<thead>
<tr>
<th>Table 5</th>
<th>Pre-Exposure SSQ Score for Each Category</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean SSQ Score</td>
</tr>
<tr>
<td></td>
<td>Pre-Exposure</td>
</tr>
<tr>
<td>Symptoms</td>
<td></td>
</tr>
<tr>
<td>Nausea</td>
<td>1.26</td>
</tr>
<tr>
<td>Oculomotor Discomfort</td>
<td>2.01</td>
</tr>
<tr>
<td>Disorientation</td>
<td>1.19</td>
</tr>
<tr>
<td>General Factors</td>
<td>0.76</td>
</tr>
</tbody>
</table>

It can be seen that the category with the maximum difference between Pre SSQ Score and Post SSQ Score is nausea followed by oculomotor discomfort followed by disorientation.

Figure 24 is a bar chart representing the data in Table 5.

Figure 24. SSQ scores by SSQ categories.
It can be observed that the subcomponent with the maximum difference between Post-Exposure and Pre-Exposure is Nausea. The order in terms of increasing SSQ Score between subcomponents is Disorientation < Oculomotor Discomfort < Nausea.

Paired t-test was performed on the mean value of SSQ score for each subject. In this test, each member of one sample has a unique relationship with a particular member of the other sample. Table 6 below shows the mean value for the SSQ scores for each of the subject. The calculated value using the paired t-test for pre-exposure and post-exposure after the first run is 0.08 and that of post exposure for the first run and the second run is 0.10. Thus the mean values are not statistically different.

<table>
<thead>
<tr>
<th></th>
<th>Pre</th>
<th>post1</th>
<th>post 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0.34</td>
<td>1.17</td>
<td>1.97</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>1.34</td>
<td>2.85</td>
<td>4.59</td>
</tr>
<tr>
<td>6</td>
<td>1.03</td>
<td>2.039</td>
<td>2.939</td>
</tr>
<tr>
<td>7</td>
<td>2.93</td>
<td>4.732</td>
<td>6.307</td>
</tr>
<tr>
<td>8</td>
<td>4.69</td>
<td>5.67</td>
<td>7.69</td>
</tr>
<tr>
<td>9</td>
<td>0</td>
<td>0</td>
<td>2.356</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>0</td>
<td>1.039</td>
</tr>
<tr>
<td>11</td>
<td>0.34</td>
<td>1.36</td>
<td>2.69</td>
</tr>
<tr>
<td>12</td>
<td>0</td>
<td>0</td>
<td>1.91</td>
</tr>
<tr>
<td>Mean</td>
<td>0.89</td>
<td>1.49</td>
<td>2.62</td>
</tr>
</tbody>
</table>

6.2.2 Analysis of Simulator Questionnaire

Each subject was asked to fill out a Questionnaire after driving each of the two Runs on the simulator, that is, static and turning seat runs. The two questionnaires had the same set of questions. Questions were about how easy was it drive on different
sections of the road. In this way, we can compare the ease with which they drove the two variations of the simulator.

The set of questions on the Simulator Questionnaire are in 3 categories. They are ease of driving on the straight section of the road, curved section of the road, and comparison with real world driving. This questionnaire is in Appendix A. The total of SQ-Scores of each category provides the total SQ-Score pertaining to that subject.

Table 7 shows the Mean Simulator Questionnaire score after the first run and after the second run. From the data it is clear that mean value of SQ Score for turning seat simulator was higher as compared to that of the static seat simulator. Although the difference is small, but it shows that subjects preferred driving turning seat simulator over static seat.

<table>
<thead>
<tr>
<th></th>
<th>Mean SQ Score</th>
<th>S.D SQ Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turning seat</td>
<td>4.58</td>
<td>1.63</td>
</tr>
<tr>
<td>Static seat</td>
<td>4.53</td>
<td>1.33</td>
</tr>
</tbody>
</table>

Figure 25 and Figure 26 are bar chart representing the mean and standard deviation of the System Questionnaire score data in Table 7.
Figure 25. Mean SQ Scores for Static and Turning seat conditions.

Figure 26. Standard deviation for static and turning seat conditions.
6.2.3 Analysis of Eye Fixation time

6.2.3.1 Total time of gaze on various elements of the environment
Table 8 shows the mean value of the total time of gaze on the various elements of the environment while driving on the left and the right normal turns for the static seat simulator.

<table>
<thead>
<tr>
<th></th>
<th>Center Marker</th>
<th>Right Edge Marker</th>
<th>Trees</th>
<th>Traffic</th>
<th>Signs</th>
<th>Sky</th>
<th>Buildings</th>
<th>Unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left Turns</td>
<td>29.2</td>
<td>26.7</td>
<td>10.6</td>
<td>0</td>
<td>1.6</td>
<td>0.8</td>
<td>0</td>
<td>31.1</td>
</tr>
<tr>
<td>Right Turns</td>
<td>13.3</td>
<td>31.9</td>
<td>10.4</td>
<td>6.7</td>
<td>0.5</td>
<td>1.3</td>
<td>1.3</td>
<td>34.6</td>
</tr>
</tbody>
</table>

Figure 27 is the bar graph representation for the time of gaze given in table 8.

It can be seen in the above graph that, apart from the unknown category, when driving the static simulator on normal curves, maximum time was spent on the center marker while driving on left curves. While driving on right curves, more time was spent on the right edge marker as compared to that while driving on left curves.
Table 9 shows the mean value of the total time of gaze on the various elements of the environment while driving on the left and the right clothoid turns for the static seat simulator.

**Table 9**

<table>
<thead>
<tr>
<th>Time of Gaze Based on Categories (Static Simulator-Clothoid Curves)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Center Marker</strong></td>
</tr>
<tr>
<td>Left Turns</td>
</tr>
<tr>
<td>Right Turns</td>
</tr>
</tbody>
</table>

Figure 28 is the bar graph representation for the time of gaze given in table 9.

In the above graph that, apart from the unknown category, when driving the static simulator on clothoid curves, maximum time was spent on the center marker while driving on left curves. While driving on right curves, maximum time was spent on the right edge marker.
Table 10 shows the mean value of the total time of gaze on the various elements of the environment while driving on the left and the right normal curves for the turning seat simulator.

<table>
<thead>
<tr>
<th></th>
<th>Center Marker</th>
<th>Right Edge Marker</th>
<th>Trees</th>
<th>Traffic</th>
<th>Signs</th>
<th>Sky</th>
<th>Buildings</th>
<th>Unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Left Turns</strong></td>
<td>21.59</td>
<td>20.56</td>
<td>5.86</td>
<td>1.29</td>
<td>4.04</td>
<td>0.00</td>
<td>0.30</td>
<td>46.36</td>
</tr>
<tr>
<td><strong>Right Turns</strong></td>
<td>18.65</td>
<td>21.74</td>
<td>5.15</td>
<td>7.98</td>
<td>2.46</td>
<td>0.00</td>
<td>4.14</td>
<td>39.88</td>
</tr>
</tbody>
</table>

Figure 29 is the bar graph representation for the time of gaze given in table 10.

![Figure 29](image-url)
Table 11 shows the mean value of the total time of gaze on the various elements of the environment while driving on the left and the right clothoid curves for the turning seat simulator.

<table>
<thead>
<tr>
<th>Turning clothoid</th>
<th>Center Marker</th>
<th>Right Edge Marker</th>
<th>Trees</th>
<th>Traffic</th>
<th>Signs</th>
<th>Sky</th>
<th>Buildings</th>
<th>Unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left Turns</td>
<td>25.99</td>
<td>24.91</td>
<td>3.54</td>
<td>1.11</td>
<td>1.96</td>
<td>1.51</td>
<td>1.70</td>
<td>39.28</td>
</tr>
<tr>
<td>Right Turns</td>
<td>18.44</td>
<td>21.85</td>
<td>7.46</td>
<td>3.58</td>
<td>1.91</td>
<td>2.99</td>
<td>0.73</td>
<td>43.04</td>
</tr>
</tbody>
</table>

Figure 30 is the bar graph representation for the time of gaze given in table 11.

The above values show that the total time of fixation on left curves was greater as compared to that of the right turn for both the center marker and the right edge marker.
6.2.3.2 Percent of Time Results For Lane Markers and Unknown

Table 12 below shows the percentage of time spent on center lane marker, right edge marker that of unknown for the normal and clothoid curves.

<table>
<thead>
<tr>
<th></th>
<th>Normal Curves</th>
<th>Clothoid Curves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center Marker</td>
<td>20.68</td>
<td>19.28</td>
</tr>
<tr>
<td>Right Edge Marker</td>
<td>25.15</td>
<td>23.72</td>
</tr>
<tr>
<td>Unknown</td>
<td>37.98</td>
<td>45.03</td>
</tr>
</tbody>
</table>

In Figure 31 is the main effect of curves (normal versus clothoid) as per the values in table 12.

![Figure 31. Percent of time by type of curve.](image)

Here, there appears to be a slight trend for drivers to look less at the road (center lane marker and right edge marker) when driving on clothoid curves.

Table 13 below shows the percentage of time spent on center lane marker, right edge
marker that of unknown for the left and the right curves.

Table 13
Percent of time by Road geometry (Left and Right Curves).

<table>
<thead>
<tr>
<th></th>
<th>Left Curves</th>
<th>Right curves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center Marker</td>
<td>23.9</td>
<td>16.1</td>
</tr>
<tr>
<td>Right Edge Marker</td>
<td>22</td>
<td>27</td>
</tr>
<tr>
<td>Unknown</td>
<td>43.1</td>
<td>40</td>
</tr>
</tbody>
</table>

In Figure 32, is the main effect of roadway geometry (left curves versus right curves) as per the values in Table 13.

![Figure 32. Percent of Time By Road Geometry (Left and Right Curves).](image)

When beginning to negotiate a left curve, drivers looked at the center lane marker and right edge marker about the same percentage of time. When beginning to negotiate a right curve, drivers looked at the right edge marker much more than the center lane.
marker. This indicates that the search and scan pattern when steering on a right curve is totally different than when steering on a left curve.

Table 14 below shows the percentage of time spent on center lane marker, right edge marker that of unknown for the normal and clothoid curves for the two variations of simulator.

<table>
<thead>
<tr>
<th></th>
<th>Static simulator</th>
<th>Turning Simulator</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Center Marker</strong></td>
<td>18.8</td>
<td>21.2</td>
</tr>
<tr>
<td><strong>Right Edge Marker</strong></td>
<td>26.7</td>
<td>22.3</td>
</tr>
<tr>
<td><strong>Unknown</strong></td>
<td>40.9</td>
<td>42.2</td>
</tr>
</tbody>
</table>

In Figure 33, is the main effect of simulator type (static versus turning seat) as per the values in Table 14.
When using the static simulator, subjects looked at the right edge marker more than the center lane marker. When using the turning seat simulator, subjects looked about the same amount of time at the right edge and center lane markers.

Table 15 shows the percentage of time spent on center marker and right edge marker while driving for the two variations of the simulator (static and turning) for the left curves.

Table 15
Percent of time by type of curve and type of simulator for left curves

<table>
<thead>
<tr>
<th></th>
<th>Center Marker</th>
<th>Right Edge Marker</th>
<th>Unknown</th>
<th>Center Marker</th>
<th>Right Edge Marker</th>
<th>Unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static simulator</td>
<td>29.2</td>
<td>26.7</td>
<td>31.1</td>
<td>18.70</td>
<td>15.68</td>
<td>55.52</td>
</tr>
<tr>
<td>Turning Simulator</td>
<td>21.59</td>
<td>20.56</td>
<td>46.36</td>
<td>25.99</td>
<td>24.91</td>
<td>39.28</td>
</tr>
</tbody>
</table>

Figure 34 presents the interaction of type of simulator and type of curve (normal vs clothoid) when only driving on left curves.

Figure 34. Percent of time by type of curve and type of simulator for left curves.
We do not know the reason for the low value of the unknown category for the normal curve / static simulator condition. It is interesting, that when entering left curves drivers gazed at the center lane and right edge markers about the same amount of time regardless of simulator type and curve type.

Table 16 shows the percentage of time spent on center marker and right edge marker while driving for the two variations of the simulator (static and turning) for the right curves.

<table>
<thead>
<tr>
<th></th>
<th>Center Marker</th>
<th>Right Edge Marker</th>
<th>Unknown</th>
<th>Center Marker</th>
<th>Right Edge Marker</th>
<th>Unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Static simulator</strong></td>
<td>13.3</td>
<td>31.9</td>
<td>34.6</td>
<td>13.97</td>
<td>32.43</td>
<td>42.31</td>
</tr>
<tr>
<td><strong>Turning Simulator</strong></td>
<td>18.65</td>
<td>21.74</td>
<td>39.88</td>
<td>18.44</td>
<td>21.85</td>
<td>43.04</td>
</tr>
</tbody>
</table>

In Figure 35, is the interaction of type of simulator and type of curve (normal vs clothoid) when only driving on right curves as per the values in Table 16.
When drivers were using the static simulator, there was a large difference in the percent of time that they viewed the type of lane marker (center or right edge). However, when the drivers were using the static simulator, they spend almost the same amount of time glancing at the center lane and right edge markers. The turning seat had a strong effect on drivers search and scan patterns when entering right curves.
6.2.3.3 Total time of gaze while driving the two types of Simulator

Table 17 below shows the total time of gaze on the straight and curved sections while driving on the normal and clothoid curves for the static simulator and the turning simulator.

<table>
<thead>
<tr>
<th>Subject Number</th>
<th>Static</th>
<th>Turning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 17
Total time of gaze on curves and straight sections while driving static and turning simulator for normal and clothoid curves

Figure 36 below is the graphical representation for Table 17.

Figure 36. Total time of gaze on static and turning simulator for normal and clothoid curves.
Results in the above graph shows that Subjects took less time to drive on clothoid curves as compared to normal curves in both turning and static seat simulator. This shows the smooth driving behavior with clothoids. Only 2 out of 12 subjects took more time to drive on clothoid curves as compared to normal curves while driving the static simulator. While in case of turning simulator, 3 out of 12 subjects took more time to drive on the clothoid curve as compared to normal curves.

Table 18 below shows the total time to drive the static and the turning simulator on both types of curves which includes the straight sections before and after the curve.

<table>
<thead>
<tr>
<th>Subject Number</th>
<th>Static</th>
<th>Turning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>391.51</td>
<td>356.33</td>
</tr>
<tr>
<td>2</td>
<td>337.35</td>
<td>370.66</td>
</tr>
<tr>
<td>3</td>
<td>337.57</td>
<td>316.93</td>
</tr>
<tr>
<td>4</td>
<td>460.34</td>
<td>362.65</td>
</tr>
<tr>
<td>5</td>
<td>289.27</td>
<td>243.17</td>
</tr>
<tr>
<td>6</td>
<td>327.17</td>
<td>277.63</td>
</tr>
<tr>
<td>7</td>
<td>343.54</td>
<td>357.55</td>
</tr>
<tr>
<td>8</td>
<td>306.68</td>
<td>229.55</td>
</tr>
<tr>
<td>9</td>
<td>323.69</td>
<td>304.86</td>
</tr>
<tr>
<td>10</td>
<td>353.05</td>
<td>373.62</td>
</tr>
<tr>
<td>11</td>
<td>201.94</td>
<td>264.01</td>
</tr>
<tr>
<td>12</td>
<td>300.11</td>
<td>309.18</td>
</tr>
</tbody>
</table>
Figure 37 is the graphical representation of Table 18.

Results in the above graph shows that subjects took more time to drive on both types of curves and the straight sections when driving static seat simulator as compared to turning seat simulator. 7 out of 12 subjects took less time to drive the turning seat simulator as compared to the static seat simulator. Therefore, results show that turning seat simulator was easier to drive on curves.
6.2.4 Analysis of Galvanic Skin Response

Table 19 shows the change in GSR when driving the static seat simulator.

![Table 19](image)

The percentage change in GSR as the cyclist appears in front of the driver suddenly was calculated as below:

\[
\text{Percentage change} = \frac{\text{Total change}}{\text{Total number of subjects}} = \frac{56}{12} = 4.66
\]

Table 20 shows the change in GSR when driving the turning seat simulator.
Table 20
GSR Value for the Turning Seat Simulator

<table>
<thead>
<tr>
<th>Subject No.</th>
<th>Base Value</th>
<th>Increased Value</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>55</td>
<td>58</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>41</td>
<td>45</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>34</td>
<td>37</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>58</td>
<td>62</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>85</td>
<td>88</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>87</td>
<td>90</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>88</td>
<td>90</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>73</td>
<td>77</td>
<td>4</td>
</tr>
<tr>
<td>9</td>
<td>47</td>
<td>51</td>
<td>4</td>
</tr>
<tr>
<td>10</td>
<td>80</td>
<td>85</td>
<td>5</td>
</tr>
<tr>
<td>11</td>
<td>80</td>
<td>84</td>
<td>4</td>
</tr>
<tr>
<td>12</td>
<td>40</td>
<td>44</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>749</strong></td>
<td><strong>805</strong></td>
<td><strong>40</strong></td>
</tr>
</tbody>
</table>

The percentage change in GSR as the cyclist appears in front of the driver suddenly is calculated as below:

\[
\text{Percentage change} = \frac{\text{Total change}}{\text{Total number of subjects}} = \frac{40}{12} = 3.33
\]

Overall change in GSR in turning seat simulator was less as compared to that of the static seat simulator. Reason for this small amount of change is discussed in the next chapter.
Figure 38 and Figure 39 are bar charts representing the change in GSR while driving the static seat simulator and the turning seat simulator respectively in Table 19 and Table 20.
Chapter 7 Discussion

Several questions were examined in this study. These questions are answered based on the data that was analyzed in the previous chapter. The key research questions that we tried to address are the following:

7.1 Did subjects feel more sickness after the experiment?

Although there was a significant increase in reported SSQ scores after experiencing the two driving trials, no subject dropped out of this study. Before driving the simulator, some had little sickness like headache. This had increased after the driving the static simulator. This had further increased after driving the second run of the experiment.

The mean difference between Pre-Exposure SSQ Score and Post-Exposure SSQ Score was statistically significant. The Mean Pre-Exposure SSQ Score is 0.89 and the Mean Post-Exposure SSQ Score is 1.49. The mean value had further increased to 2.62. Hence, this data set shows that the after exposure scores were higher than pre-exposure scores. The order in terms of increasing SSQ Score between subcomponents is Disorientation < Oculomotor Discomfort < Nausea.

7.2 Which type of Simulator was easier to drive on curves?

According to the simulator questionnaire, half of the subjects preferred static simulator when driving on the curves and vice versa. Total time subjects took to drive
on the two types of curve using a static seat simulator and turning seat simulator was analyzed. Results show that 8 out of 12 subjects took more time to drive on normal curves when driving static seat simulator as compared to turning seat simulator. Also, 7 out of 12 subjects took more time to drive on curves with clothoid when driving static seat simulator as compared to turning seat simulator. The mean value for the simulator questionnaire is slightly different statistically. Mean for turning seat simulator is 4.58 and that for the static seat simulator is 4.53.

Driving Simulator.

### 7.3 Which curves, clothoid or without clothoid, were easier to drive on?

Total times while driving on curves with clothoid and without clothoid are calculated for each of the 12 subjects. Results show that the time for 10 out of 12 subjects for driving on clothoid is found to be less as compared to driving on the normal curves in case of static seat simulator. Also, time for 9 out of 12 subjects for driving on clothoid is found to be less as compared to driving on the normal curves in case of turning seat simulator.

Clothoids are useful curves for generating smooth trajectories as they result in a smooth transition between straight-line segments and circles. Analysis of the average speed at all groups of curves with and without clothoids shows the same tendency: curves without clothoids were driven at lower speed, than the same geometry curves with clothoids.
Therefore, the effectiveness of using clothoids is recognized, thus allowing smooth safer driving behavior on curves with clothoids.

7.4 Pattern of eye movement.

In curved sections, there was a tendency to fixate on one of the edges of the road. Based on the test, in both left and right curves, there is a trend for the drivers to look less at the center lane marker or right edge marker when driving on clothoid curves. When driving on the left curve, total percentage time of gaze on the center lane marker and the right edge marker is almost the same. Whereas, while driving on the right curve, fixation shifts to the right edge marker much more as compared to the center lane marker. This clearly shows that the search pattern on the two types of curves is different.

Results show that when driving the turning seat simulator on the normal right curves, almost same amount of time was spent on center lane marker and on right edge marker. While in static seat, less amount of time was spent on center lane marker and comparatively is almost 20 percent less than the time spent on right edge marker. This trend is also seen when driving on the clothoid right turns. Whereas in case of left curves (both clothoid and normal), almost same amount of time was spent at the center lane marker and on the right edge marker. This is regardless of the type of curve and also the type of simulator.

Results also show that when driving the static seat simulator, total percentage of time subjects looked at the right edge marker was more as compared to that on the center
lane when noted regardless of the type of curve. When driving the turning seat simulator, total percentage of time spent on right edge marker and center lane marker was almost the same.

Subject looked at random locations from time to time to observe the scenario. This behavior was observed while approaching curves to the right or to the left. The eye movement could not be tracked a number of times, this was because of occlusion. When approaching the curved sections, the eye glance shifts towards the start of the curve. In curved sections, the focus was mostly on the edge of the road.

Also, it can be seen from the data the mean duration of fixation in the curve to the left was more as compared to the right in both type of simulators.

7.5 Change in GSR

Results of the subjective evaluation showed that there is a difference between the static and the turning seat driving simulator conditions. This shows that GSR plays a big part in recognizing emotions. GSR is highly sensitive to emotions. So, fear, startle response produce a GSR response. Comparing the result of the pre-test with the post-test under sudden unexpected conditions, it was found that subjects feel tension under dangerous driving conditions. This shows that human sense organs respond in a different way for different conditions, which can be measured.

Overall increase in GSR, in case of the static seat simulator, is greater as compared to that of the turning seat simulator. Mean value of the change in GSR for the static seat simulator is 4.66 is much higher as compared to the 3.33 in case of turning seat
simulator. Continuous activity of the body results in an increase in the base value of GSR. So the startle response, when the cyclist appears in front of the driver, results in a slight increase in GSR in case of the turning seat simulator.
Chapter 8 Future Research

“If we knew what it was we were doing, it would not be called research, would it?”
-- Albert Einstein

8.1 Tracking the eye movements while driving on upwards and downwards slope.

This study involved tracking the eye movements while driving on horizontal curves. Results show that while driving on the horizontal curves the eye movement shift to the surrounding environment. This can be extended to include eye movements while driving on the sloppy roads, which means, upward and downward slope. This would provide useful information for real-world driving situations because road geometry could be one of the reasons for accidents.

8.2 Design curves with up-slope and down-slope using Clothoids.

The only kind of curve in this study is the horizontal curve. This can be, in future, extended to designing sloping curves, both upwards and downwards like highway ramps. Such scenarios will be useful in determining driver performance, which can further be used to improve the road designs. This will also provide useful information for improving real world driving situations in the hilly regions as well.
8.3 Variation of GSR over a longer time

This study involved measurement of GSR when a bicyclist suddenly appears in front of the driver. However, measuring the value of GSR over the complete course of the scenario may produce interesting results. Analyzing this data would give us information about the psychological state of the driver. This would help in finding the cause of simulator sickness.

8.4 Adding scenarios to the simulation

The only kind of scenario in this study was that the subject was asked to obey the traffic signs. However, more scenarios could be developed to test drivers’ performance. Temptation scenarios can be added to the environment. Such scenarios will be useful in determining driver performance. An example of temptation scenario could be having a lead vehicle cross the traffic light when it is red.
References


Web links

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Appendix A: Subject Forms

1. Background Information Form

Project Title: Driver Performance on Curves Using a Driving Simulator

Name of Investigator: Ronald Mourant and Sonali Gupta

Date: ___________

Subject Number ______

First Name: _____________________         Last Name: ____________________________

Email:              ____________________________________

Phone:             _______________________

Background Information

1. Date of Birth:   Month_____ Day _____ Year____

2. Gender:   MALE   FEMALE

3. Driving Experience:
   a. When did you first obtain your driving license?   Year____
   b. Miles you drove last year?   _____ miles
   c. What is your corrected visual acuity?      ________________
   d. Do you wear while driving   a) glasses    b) contact lenses    c) None
   e. Are you wearing your glasses or contact lenses right now?   ____YES ___NO
      (If not please do so)
   f. Please indicate all medications you have used in the past 24 hours. If none, check the first line:
      a) NONE     ____________
      b) Sedatives or tranquilizers     ____________
      c) Aspirin, Tylenol, other analgesics    ____________
      d) Anti-histamines     ____________
      d) Decongestants     ____________
      e) Other (specify):     ____________
2. *Simulator Sickness Questionnaire*

Subject number ________      Date ____________

Please Check One:  Before Testing__________         After Testing _____________

Circle how much each symptom below is affecting you **right now**.

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<th>Symptom</th>
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<th>Slight</th>
<th>Moderate</th>
<th>Severe</th>
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<td>Fatigue</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>3</td>
<td>Boredom</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Drowsiness</td>
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<td>Headache</td>
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<td>Difficulty focusing</td>
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</tr>
<tr>
<td>8</td>
<td>a) Salivation increased</td>
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</tr>
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<td>9</td>
<td>b) Salivation decreased</td>
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<tr>
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<td>Difficulty concentrating</td>
<td></td>
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<td></td>
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<td>Mental depression</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Fullness of the head</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>15</td>
<td>Blurred vision</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>a) Dizziness with eyes open</td>
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<td></td>
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<tr>
<td>17</td>
<td>Visual flashbacks**</td>
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<td>Aware of breathing</td>
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<tr>
<td>20</td>
<td>Stomach awareness***</td>
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<tr>
<td>27</td>
<td>Other</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Vertigo is experienced as loss of orientation with respect to vertical upright.
** Visual illusion of movement or false sensations of movement, when NOT in a simulator, car, or aircraft.
*** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

Describe other: ___________________________________ _______________
3. System Questionnaire

Subject Number ______                       Static seat______                       Turning seat_____

Using the seven point scale provided please answer the following questions by placing an ‘X’ on the lines below.

1) How easy was it to steer the vehicle when driving on the straight portions of the road?

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<thead>
<tr>
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<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
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<tbody>
<tr>
<td>Poor</td>
<td></td>
<td></td>
<td>Neutral</td>
<td></td>
<td></td>
<td>Excellent</td>
</tr>
</tbody>
</table>

2) How easy was it to steer the vehicle when driving on the curved paths?

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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</thead>
<tbody>
<tr>
<td>Poor</td>
<td></td>
<td></td>
<td>Neutral</td>
<td></td>
<td></td>
<td>Excellent</td>
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</tbody>
</table>

3) How easy was it to maintain the speed limit of 45 mph while driving on the straight portions of the road?

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<th>6</th>
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</thead>
<tbody>
<tr>
<td>Poor</td>
<td></td>
<td></td>
<td>Neutral</td>
<td></td>
<td></td>
<td>Excellent</td>
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</table>

4) How easy was it to maintain the speed limit of 35 mph while driving on the curved paths?

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<td></td>
<td></td>
<td>Neutral</td>
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<td></td>
<td>Excellent</td>
</tr>
</tbody>
</table>

5) How realistic was your simulator experience as compared to real world driving?

<table>
<thead>
<tr>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
<td></td>
<td>Neutral</td>
<td></td>
<td></td>
<td>Excellent</td>
</tr>
</tbody>
</table>
4. End of Experiment Questionnaire

Subject Number ________________

Circle a or b below. I prefer driving with the

   a) Simulator static (fixed in place)
   b) Simulator rotating as I drove on curves

Circle c or d below. Was steering more realistic with the

   c) Simulator static
   d) Simulator rotating as I drove on curves

What was your overall reaction to the static simulator? What do you like and not like about it?

What was your overall reaction to the turning simulator? What do you like and not like about it?
Appendix B: Raw Data

1. Pre-Exposure SSQ Score Data

<table>
<thead>
<tr>
<th>Subject No:</th>
<th>Nausea</th>
<th>Oculomotor Discomfort</th>
<th>Disorientation</th>
<th>General Factors</th>
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</thead>
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2. Post-Exposure SSQ Score Data (After run 1)

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### 3. Post-Exposure SSQ Score Data (After run 2)

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</table>

### 4. Total time of gaze on different elements of the environment while driving on the normal Curves (static seat simulator):

<table>
<thead>
<tr>
<th>Subject Number</th>
<th>On center lane marker</th>
<th>On the edge of the road</th>
<th>Sign</th>
<th>Tree</th>
<th>Sky</th>
<th>Traffic</th>
<th>Buildings</th>
<th>Unknown</th>
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6. Total time of gaze on different elements of the environment while driving on the clothoid curves (turning seat simulator):

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7. Total time of gaze on different elements of the environment while driving on the normal Curves (turning seat simulator):

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Appendix C: Code

1. Clothoid Curve

The code below was partially based on the work of McCrae and Singh (2008) (Source: Sketching Piecewise Clothoid Curves).

The arguments that are passed to the method are start point(ps), width of the road to be drawn(w), image filename that is to be used to draw the road segment(imageFileName) and the segment number(SegNum).

```cpp
void whiteline::populateClothoidSeg(const Point3f& ps, float w, const char* imageFileName, int SegNum)
{
    int index = numOfwhitelineegs;
    char fileName[MAX_STRING_LEN];
    float xdev, zdev, xfactor, zfactor;
    strcpy(fileName, TEXTURE_BASED);
    strcat(fileName, imageFileName);

    for (int t=0; t<=80; t++)
    {
        float t1=(float)t/100;
        float R=(0.506*t1+1)/(1.79*t1*t1+2.054*t1+sqrt(2)); // [Source: Sketching Piecewise Clothoid Curves]
        float A=1/(0.803*t1*t1*t1+1.886*t1*t1+2.524*t1+2); // [Source: Sketching Piecewise Clothoid Curves]
        St[Num]=-150*PI*(0.5-R*sin(0.5*PI*(A-t1*t1)))); // [Source: Sketching Piecewise Clothoid Curves]
        Ct[Num]=150*PI*(0.5+R*cos(0.5*PI*(A-t1*t1)))); // [Source: Sketching Piecewise Clothoid Curves]

        if (Num>0)
        {
            PieceLength[Num] = sqrt((Ct[Num]-Ct[Num-1])*(Ct[Num]-Ct[Num-1])+(St[Num]-St[Num-1])*(St[Num]-St[Num-1]));
            ArcLength[Num]= PieceLength[Num]+ArcLength[Num-1];
            Road_angle=asin((Ct[Num]-Ct[Num-1])/PieceLength[Num]);
        }
        else if(Num==0)
        {
            PieceLength[Num]=0;
            ArcLength[Num]=0;
            Road_angle=0;
        }
        xInner[Num]=w*cos(Road_angle);
        yInner[Num]=w*sin(Road_angle);

        //printf("ct is%d %f %f %f %f\n",Num,
        Ct[Num],St[Num],Road_angle*180/PI,xInner[Num],yInner[Num]);
        Num++;
    }
    if(SegNum==1)
    {
```

```
xfactor=1;
zfactor=1;
xdev=0.0;
zdev=0.0;
}

else if(SegNum==2)
{
xfactor=-1;
zfactor=-1;
xdev=235.4359;
zdev=-340.263458*2;
}
else if(SegNum==3)
{
xfactor=-1;
zfactor=1;
xdev=0.0;
zdev=0.0;
}
else if(SegNum==4)
{
xfactor=1;
zfactor=-1;
xdev=0.0;
zdev=0.0;
}

FILE *fp;

for (int i=0;i<80;i++)
{
  int j = 0, k = 0;
  numOfwhitelineegs++;
  initTextureObject(fileName);
  //inner end point
  vertices_white[index*4*3+(j++)] = ps.x*xfactor*(Ct[i+1]+xInner[i+1])+xdev;
  vertices_white[index*4*3+(j++)] = ps.y;
  vertices_white[index*4*3+(j++)] = ps.z+zfactor*(St[i+1]+yInner[i+1])+zdev;
  //inner start point
  vertices_white[index*4*3+(j++)] = ps.x+xfactor*(Ct[i]+xInner[i])+xdev;
  vertices_white[index*4*3+(j++)] = ps.y;
  vertices_white[index*4*3+(j++)] = ps.z+zfactor*(St[i]+yInner[i])+zdev;
  //outer start point
  vertices_white[index*4*3+(j++)] = ps.x*xfactor*(Ct[i]+xInner[i]+xdev);
  vertices_white[index*4*3+(j++)] = ps.y;
  vertices_white[index*4*3+(j++)] = ps.z+zfactor*(St[i]+yInner[i]+zdev);
  //outer end point
  vertices_white[index*4*3+(j++)] = ps.x*xfactor*(Ct[i+1]-xInner[i])-xdev;
  vertices_white[index*4*3+(j++)] = ps.y;
  vertices_white[index*4*3+(j++)] = ps.z+zfactor*(St[i+1]-yInner[i])-zdev;
  if(i%13==0)
2. Normal Curve

Following is the code for creating normal curved section of roads. The arguments that are passed to the method are start point(ps), end point(pe), point through which the curve passes(pc), width of the road to be drawn(w), image filename that is to be used to draw the road segment(imageFileName) and the number of tiles for which the road should be drawn(numTiles).

```cpp
void whiteline::populateCurvedRoad(const Point3f& ps, const Point3f& pe, const Point3f& pc, float w, const char* imageFileName, int numTiles)
{
    int index = numOfwhitelineegs;
    float radius = pc.distance(ps);
    float r1 = radius-w/2;
    float r2 = radius+w/2;

    Point3f ps_pc;
    Point3f pe_pc;
    ps_pc.sub(ps, pc);
    pe_pc.sub(pe, pc);

    float ps_pc_slope = ps_pc.z/ps_pc.x;
    float pe_pc_slope = pe_pc.z/pe_pc.x;

    float theta = atan( (pe_pc_slope-ps_pc_slope)/(1+ps_pc_slope*pe_pc_slope));
    if (!strcmp(str, "nan"))
        theta = M_PI_2;
    if (theta<0)
```
theta *= -1;

float angWithXAxis = -atan(ps_pc_slope);
sprintf(str,"%f", angWithXAxis);
if (!strcmp(str,"nan"))
angWithXAxis = M_PI_2;

Point3f calc_ps;
calc_ps.x = pc.x + radius*cos(angWithXAxis);
calc_ps.y = ps.y;
calc_ps.z = pc.z - radius*sin(angWithXAxis);

if (calc_ps.distance(ps) > 0.1f)
angWithXAxis = M_PI+angWithXAxis;

float stepAng = theta/numTiles;
float deltaY = (ps.y - pe.y) / numTiles;

strcat(whitefileName, imageFileName);
for (int i = 0; i<numTiles; i++)
{
    int j = 0, k = 0;
    numOfwhitelineegs++;
    initTextureObject(whitefileName);

    //inner end point
    vertices_white[index*4*3+(j++)] = pc.x + r1*cos(angWithXAxis+stepAng*(i+1));
    vertices_white[index*4*3+(j++)] = pc.y + (i+1)*deltaY;
    vertices_white[index*4*3+(j++)] = pc.z - r1*sin(angWithXAxis+stepAng*(i+1));

    //inner start point
    vertices_white[index*4*3+(j++)] = pc.x + r1*cos(angWithXAxis+stepAng*i);
    vertices_white[index*4*3+(j++)] = pc.y + i*deltaY;
    vertices_white[index*4*3+(j++)] = pc.z - r1*sin(angWithXAxis+stepAng*i);

    //outer start point
    vertices_white[index*4*3+(j++)] = pc.x + r2*cos(angWithXAxis+stepAng*i);
    vertices_white[index*4*3+(j++)] = pc.y + i*deltaY;
    vertices_white[index*4*3+(j++)] = pc.z - r2*sin(angWithXAxis+stepAng*i);

    //outer end point
    vertices_white[index*4*3+(j++)] = pc.x + r2*cos(angWithXAxis+stepAng*(i+1));
    vertices_white[index*4*3+(j++)] = pc.y + (i+1)*deltaY;
    vertices_white[index*4*3+(j++)] = pc.z - r2*sin(angWithXAxis+stepAng*(i+1));

    glBindTexture(GL_TEXTURE_2D, *tList);

    textureCoords_white[index*4*2+(k++)] = 1.0f;
    textureCoords_white[index*4*2+(k++)] = 0.0f;
    textureCoords_white[index*4*2+(k++)] = 1.0f;
    textureCoords_white[index*4*2+(k++)] = 1.0f;
3. Straight road

Following is the code for creating straight sections of roads. The arguments that are passed to the method are start point \((ps)\), end point \((pe)\), width of the road to be drawn \((w)\), image filename that is to be used to draw the road segment \((imageFileName)\) and the number of tiles for which the road should be drawn \((numTiles)\).

```cpp
void whiteline::populateRoadSeg(const Point3f& ps, const Point3f& pe, float w, const char* imageFileName, int numTiles)
{
    ang = 0.0f;
    j = 0;
    k = 0;
    index = numOfwhitelineeegs++;

    strcpy(whitelineName, TEXTURE_BASED);
    strcat(whitelineName, imageFileName);
    initTextureObject(whitelineName);

    totalL = sqrt((ps.x - pe.x)*(ps.x - pe.x) + (ps.z - pe.z)*(ps.z - pe.z));

    if(pe.x == ps.x)
        ang = M_PI_2;
    else
        ang = acos((pe.x - ps.x) / totalL);

    deltaX = (w/2)*sin(ang);
    deltaZ = (w/2)*cos(ang);

    vertices_white[index*4*3+(j++)] = pe.x - deltaX;
    vertices_white[index*4*3+(j++)] = pe.y;
    vertices_white[index*4*3+(j++)] = pe.z - deltaZ;

    vertices_white[index*4*3+(j++)] = ps.x - deltaX;
    vertices_white[index*4*3+(j++)] = ps.y;
    vertices_white[index*4*3+(j++)] = ps.z - deltaZ;

    vertices_white[index*4*3+(j++)] = ps.x + deltaX;
    vertices_white[index*4*3+(j++)] = ps.y;
    vertices_white[index*4*3+(j++)] = ps.z + deltaZ;

    vertices_white[index*4*3+(j++)] = pe.x + deltaX;
    vertices_white[index*4*3+(j++)] = pe.y;
    vertices_white[index*4*3+(j++)] = pe.z + deltaZ;

    if( numTiles == -1 )
        numTiles = (int) (totalL / w);
    glBindTexture(GL_TEXTURE_2D, *tList);
}
```
textureCoords_white[index*4*2+(k++)] = 1.0f;
textureCoords_white[index*4*2+(k++)] = 0.0f;
textureCoords_white[index*4*2+(k++)] = 1.0f;
textureCoords_white[index*4*2+(k++)] = numTiles;
textureCoords_white[index*4*2+(k++)] = 0.0f;
textureCoords_white[index*4*2+(k++)] = numTiles;
textureCoords_white[index*4*2+(k++)] = 0.0f;
textureCoords_white[index*4*2+(k++)] = 0.0f;
}

4. Autonomous Vehicles
The following is the structure of the autonomous vehicles class.

```cpp
class AutoVehicle
{
private:
    Ms3DModel* pModel; //Name of the model
    char autoIndex[NAME_MAX]; //index
    GLfloat scaling; //scaling values of the model
    GLfloat initRotation; //angle of rotation
    Point3f orientation; // initial orientation angle
    Point3f location; //initial position of the vehicle
    Point3f currentLocation; //present location of the vehicle
    GLfloat speed; //velocity of the vehicle
    GLfloat travelDistance; //Distance to travel
    GLfloat elapsedTime;
    GLfloat elapsedDistance;
    GLfloat currentSpeed;
    GLfloat acceleration;
    GLfloat deceleration;
    GLfloat distanceLight;
    TrafficLight* curLight;
    bool passed; // To figure the position of the vehicle
    int laneIndex;
public:
    AutoVehicle(char* autoIndex, GLfloat scaling, GLfloat initRotation, Point3f orientation, Point3f location, int laneIndex);
    ~AutoVehicle();
    void renderLeadingVehicle(Uint32 currTick, Uint32 lastTick);
    void renderFollowingVehicle(AutoVehicle* pVehicle, Uint32 currTick, Uint32 lastTick);
    Ms3DModel* getModel(){return pModel;};
    void setModel(Ms3DModel* vModel){ pModel = vModel;};
    Point3f getCurrentLocation(){return currentLocation;};
    TrafficLight* AutoVehicle::getTrafficLightInfo(Point3f location);
    int getCurStatus(){return curStatus;};
    void setCurStatus(int status){curStatus=status;};
    GLfloat distanceToLine(Point3f pt, Point3f ps, Point3f pe);
};
```

5. Signs and trees
For a building, the values needed are the position, scaling factor, rotation and the texture of the front, side and roof. Following is the structure of the Buildings class.

```cpp
class BuildingInstance {
private:
};
```
GLfloat x;
GLfloat y;
GLfloat z;
GLfloat rot_y;
GLfloat scaleX;
GLfloat scaleY;
GLfloat scaleZ;
int buildingModel;
GLuint textureFront;
GLuint textureSide;
GLuint textureRoof;
GLuint isbuild;//for divider
public:
    BuildingInstance(GLfloat x, GLfloat y, GLfloat z, GLfloat scaleX,
    GLfloat scaleY, GLfloat scaleZ, GLfloat rot_y, int buildingModel,
    GLuint textureFront, GLuint textureSide, GLuint textureRoof, GLuint
    isbuild) {
        this->x = x;
        this->y = y;
        this->z = z;
        this->scaleX = scaleX;
        this->scaleY = scaleY;
        this->scaleZ = scaleZ;
        this->rot_y = rot_y;
        this->buildingModel = buildingModel;
        this->textureFront = textureFront;
        this->textureSide = textureSide;
        this->textureRoof = textureRoof;
        this->isbuild = isbuild;//for divider
    }

    void setBuildingInstance(GLfloat x, GLfloat y, GLfloat z, GLfloat
    scaleX, GLfloat scaleY, GLfloat scaleZ, GLfloat rot_y, int
    buildingModel, GLuint texture, GLuint textureFront, GLuint
    textureSide, GLuint textureRoof, GLuint isbuild) {
        this->x = x;
        this->y = y;
        this->z = z;
        this->scaleX = scaleX;
        this->scaleY = scaleY;
        this->scaleZ = scaleZ;
        this->rot_y = rot_y;
        this->buildingModel = buildingModel;
        this->textureFront = textureFront;
        this->textureSide = textureSide;
        this->textureRoof = textureRoof;
        this->isbuild = isbuild;//for divider
    }

    GLfloat getX() { return x; }
    GLfloat getY() { return y; }
    GLfloat getZ() { return z; }
    GLfloat getScaleX() { return scaleX; }
    GLfloat getScaleY() { return scaleY; }
    GLfloat getScaleZ() { return scaleZ; }
    GLfloat getRot_y() { return rot_y; }
    int getBuildingModel() { return buildingModel; }
    int getTextureFrontIndex() { return textureFront; }
    int getTextureSideIndex() { return textureSide; }
    int getTextureRoofIndex() { return textureRoof; }
    GLuint getisbuild() { return isbuild; }//for divider
};