Virtual reality driving simulator for analysis of user response time

By

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ABSTRACT

The purpose of this master's thesis is to investigate and analyze the ability of individual users of a virtual reality (VR) driving simulator to react to a set of complex scenarios involving various accident-prone scenarios in a mixed virtual environment. The virtual environment is realistic enough to examine the response times in complex scenarios, and to identify the response time taken and the factors affecting it. The final result identifies the response time and represented the correlation between demographics and the driver's behavior.

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Chapter 1-Introduction

Recent Studies have indicated that the implementation of virtual reality (VR) technology in driving simulation has increased drastically. Apart from this domain, VR applications are also being applied in clinical, educational and research purposes as well. Recent studies using VR have shown increases in responsiveness, quality of service, photorealism, and other aspects of environmental realism (Sabrina, Bailenson & Huang, 2019). Although there has been intensive growth in VR applications on driving studies (Zhao & QinPing, 2009), relatively little quantitative research has been done to identify and analyze the gap between an individual's ability to react to complex scenarios and challenges in various weather conditions, especially using affective computing methods and biometric instrumentation (Riva & Guiseppe, 2002).

Driving an automobile is a complex and focused task that actively involves all cognitive factors such as perception, visualization and very good decision-making skills. Assessing drivers' skills in real life is quite challenging as it is not cost-effective and quite dangerous. There is a need for better approaches which are easy, reliable and cost-effective to make this assessment. Virtual reality is a very realistic, promising, and evolving technology which makes developing simulations to assess skills easy and very cost-effective.

According to NHTSA annual reports, there is an average increase of 3.4% in pedestrian-related fatalities every year and there is an average increase of 3% in automobile-related fatalities for the last decade.

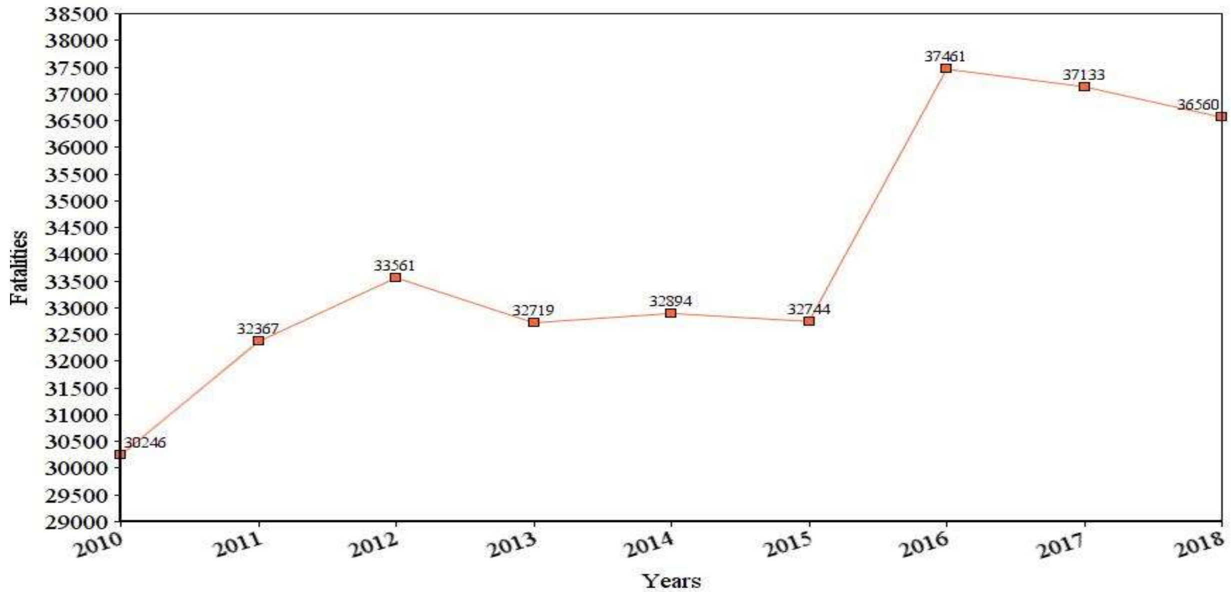

Figure 1.1 Line plot of NHTSA automobile fatalities, 2010 – 2018.

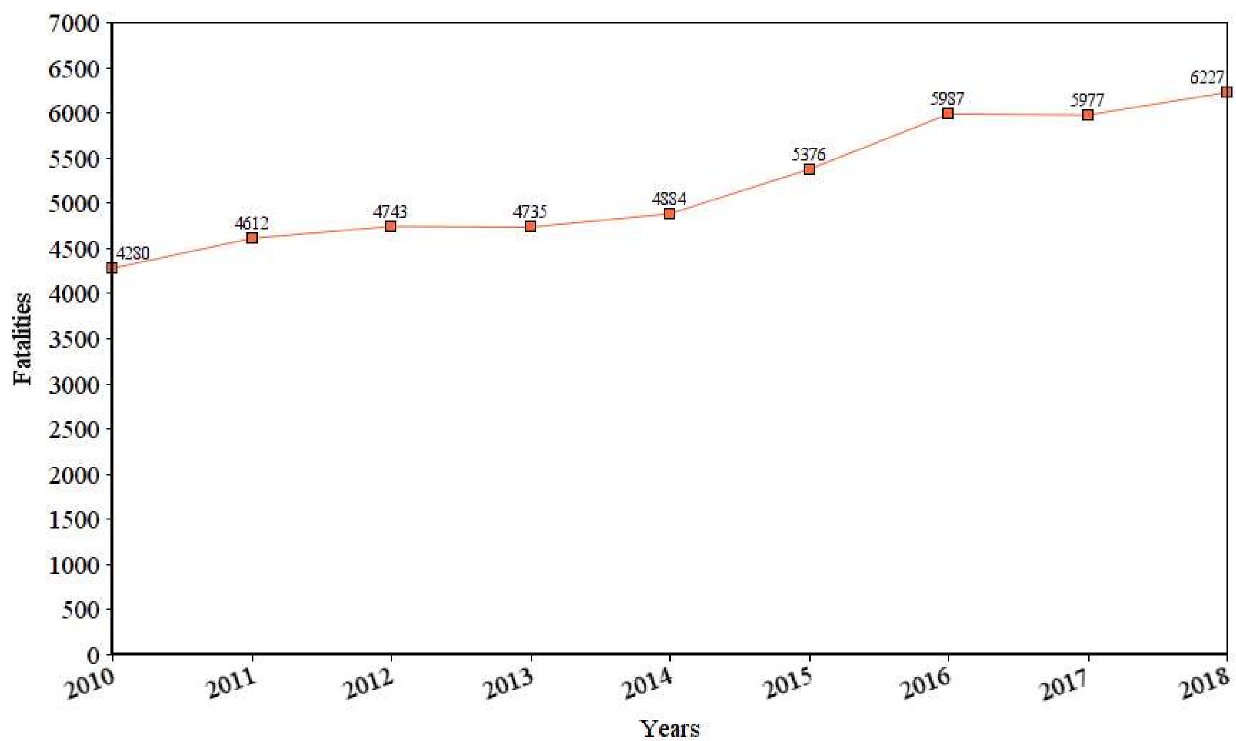

Figure 1.2 Line plot of NHTSA pedestrian-related fatalities, 2010 – 2018.

This work aims to identify and analyze the reaction time of a driver operating a VR simulator and the factors affecting this reaction time, by using a 3-Dimensional virtual environment implemented using virtual reality technologies.

Chapter 2 – Background and Related Work

There have been a lot of advancements recently in virtual reality driving simulators which made performing assessments, and training individuals relatively easy and cost-effective. Using virtual reality, the problem of improving driving behavior, by using simulation for practice and for critiquing, has improved drastically hence reducing human intervention and cost associated with it. According to Pantelidis, Veronica (2009), The major advantage of this virtual reality environment is that it generates a real-life incident to exactly simulate for training purposes.

Taheri and Kojiro Matsushita (2017) has presented on working on measuring driver behavior using virtual reality driving simulation using an HTC Vive virtual reality headset which was powered by SteamVR and used Unity to design their scenarios. Data for this experiment is gathered from 10 participants aging between 19-35 (van Leeuwen, Happee and de Winter, 2015). To analyze the data MATLAB was used where the result of this research indicates the behavior of every participant. The main disadvantage of this is the graphics which are of low quality and not realistic, and he did not consider many aspects of the road in order to practice (van Leeuwen, Happee and de Winter, 2015). According to Blissing, Bruzelis and Eriksson (2019), driving simulators offer an almost completely controlled environment where an HMD is used. Multiple HMD based setups have been installed and compared the driver behavior between them. Video see through and pure virtual reality setups have been used to conduct various tests where the participants must drive at low speed while the data of the vehicle is been recorded.

According to Summala, Heikki (2000), many research studies have been conducted to analyze the behaviour of drivers in various scenarios. Unfortunately, most of the studies have low-quality 3-D environment, which is not realistic and responsive, which ultimately affects the results. There is also a dearth of research on biometric research to identify the reaction time in accident-prone scenarios and account for correlation between driver behavior and driver demographics.

Chapter 3 – Technical Background

In this study, a number of technical hardware and software tools have been used. These tools are used to create virtual environment for this study The list of software and hardware tools are mentioned in this chapter to give an understanding to the reader of what tools and technologies made this study possible.

3.1 Oculus Rift VR Headset

The main VR headset used for the study is the Oculus Rift VR headset, which is an advanced personal computer (PC)-driven headset with immersive environment rendering and eye-tracking capabilities. The Oculus Rift VR headset consists of 2 dedicated location tracking sensors which provide seamless projections of the virtual environment through two lenses in the VR headset. Although there are many other VR headset manufacturers on the market, a decision to use the Oculus VR was made because of its ease of use, simplicity of application programmer interface (API), and eye-tracking capabilities.

Figure 3.1: Hardware components of oculus rift VR headset

The Oculus Rift has two 1080 x 1200 pixels for projection and has built-inbuilt-in accelerometer, gyroscope, and 360-degree positional tracking capabilities combined with a great Field of View (FOV) of 110 degrees.

3.2 Unity game engine

Unity is a 3-D game engine used to develop high-quality video games on various platforms such as mobile, VR/AR, desktop and on console platforms. Unity is free to use for personal and research use, which made it a great choice for this study. Unity also supports numerous free 3-D assets. Also, Unity has various built-in optimization tools which are used to achieve desired frame rates.

3.3 Blender

Blender is an open-source, cross-platform 3-D model creation software library. It is used in this study to build, edit, optimize 3-D models. It is easy to use and has very good documentation which made it an ideal choice for this research study.

3.4 Xbox Controller

A Microsoft Xbox wireless controller was used as the main controller to control the automobile in the study environment. This is a wireless controller that provides highly responsive inputs to the model with minimal latency.

Figure3.2: The Microsoft Xbox wireless controller

3.5 Empatica E4 Wristband

The Empatica E4 wristband is a medical class 2 device (Overview of Device Regulation, 2018) used to gather record blood volume pulse in real time (Empatica E4 data rate, n.d). It is mainly used to record heartbeat which is alter used to relate correlate with accident-prone scenarios in the study environment.

Figure 3.3: The Empatica E4 Wristband

Chapter 4 – Research Method

This chapter will discuss the workflow model and the experiment design and implementation processes of this project in more detail. This study comprises two parts, conducted in a controlled environment. Part 1 of the study consists of a series of questionnaires and color-blindness tests administered through a desktop web browser. These questionnaires are designed to collect and determine any correlation between participants with different demographics and also information relevant to driver's past driving history. In part 2 of the study, subjects were administered through a 3-D virtual environment in virtual reality headset. After completing their exercise within the virtual environment, subjects are redirected to a short survey designed to collect feedback and experience in the virtual environment which can be used to further tune in or develop a virtual environment for future studies.

4.1 Participant recruiting

Subjects were recruited from the university campus through posters placed in the student union, department of Architecture, university announcements, and via email sign-up. The email sign-up survey listed a couple of pre-conditions for the study, which are: 1) participant should be above 18 years of age, 2) participant does not any visual impairments. The only knowledge these subjects had was about to participate in Virtual reality (VR) simulation while we measure heartbeat and response time. Each subject received a monetary amount of a $15 gift card as the form of compensation for their time spent on this study. To comply with the university Institutional Review Board (IRB) policy, each subject was assigned a random five-digit unique number to preserve their anonymity.

4.2 Experiment design

Subjects have to fill out the survey which reported basic demographic questions and was administered a series of color-blindness test via desktop. A total of 27 Ishihara plates are included in Ishihara's color-blindness to evaluate subject's capacity to identify different colors which plays a crucial role in evaluating their performance.

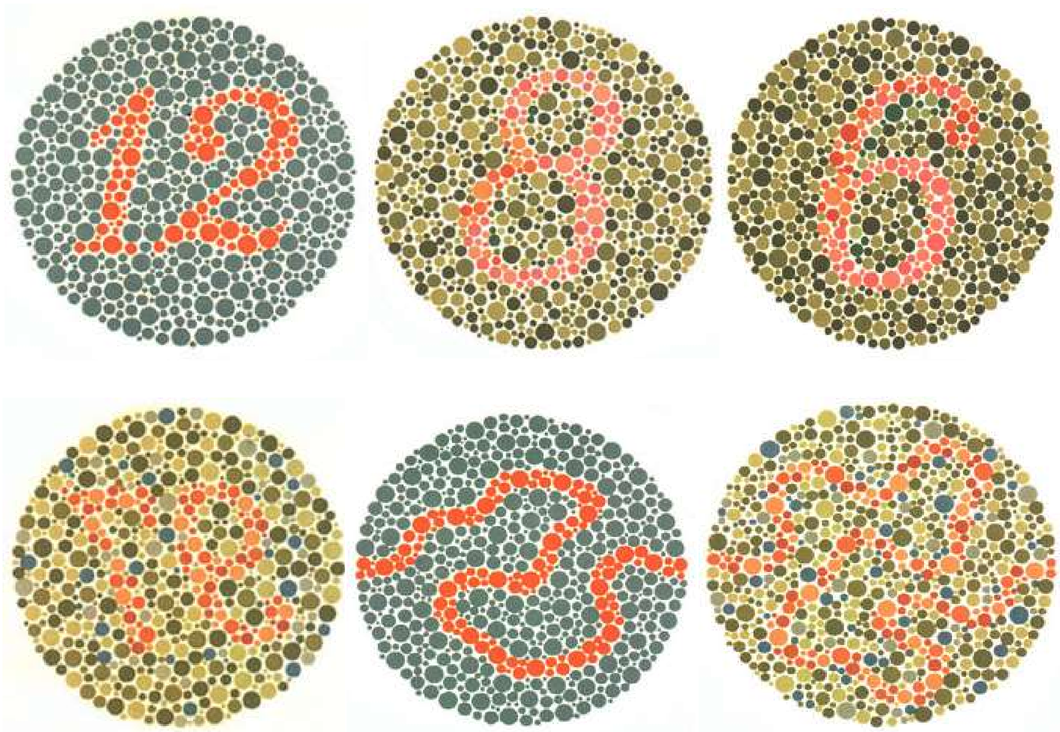

Figure 4.1 Ishihara color blindness test plates

In part 2 of the study, each subject was equipped with a gaming laptop, Oculus Rift VR headset, and a controller to navigate through the virtual environment. Also, subjects were equipped with the Empatica E4 wristband to record their heartbeat. While wearing the VR headset, subjects were navigated through a small demonstration of instructions and a demo scene to make them comfortable with the controls and visual aspects before entering into the study virtual environment. After completion of the demo scene, they were redirected to the main study scene where they have to navigate through the environment in a first-person perspective of the vehicle and were administered through several complex driving scenarios. A Xbox controller was used in this study to make subjects use the controls effectively. The left thumbstick of the controller was configured for forward and backward motion, and the right thumbstick was configured for adjusting angle/viewing direction. Alternatively, subjects could change their viewing angles though the VR headset itself.

The demo virtual environment introduced subjects to visuals cues such as roads, vegetation, arrows used for navigation that are part of the study virtual environment. Movement in the study and virtual environment was constrained by implementing invisible walls all over the designated travel path to ensure that the subjects will stick only to the navigation path and do not wander around the environment. After the driving exercise for this study was completed, eye tracking information was saved on to the local desktop and subjects were instructed to remove their Empatica E4 wrist bands. The wrist band session data in the form of .csv format is downloaded via Empatica web portal to the local machine for further analysis. Part 2 of the study took approximately 20 – 25 minutes to complete.

4.3 Virtual environment and Interface

I used the Unity 3-D game engine for this research study as it provides several key benefits. First, it allowed the implementation of different climates within the virtual environment and permitted analysis of individual features of the virtual environment that could be associated with eye-tracking data. The study virtual environment was mainly designed for an immersive experience. It comprised of four 5x5 blocks with a mix of urban environments (residential, commercial, and industrial) and highway environment to make it relatively close to real-life driving simulation. Subjects navigate through a fixed route using the Xbox controller.

Figure 4.2 First person view of the subject

Figure 4.3 Commercial district scene

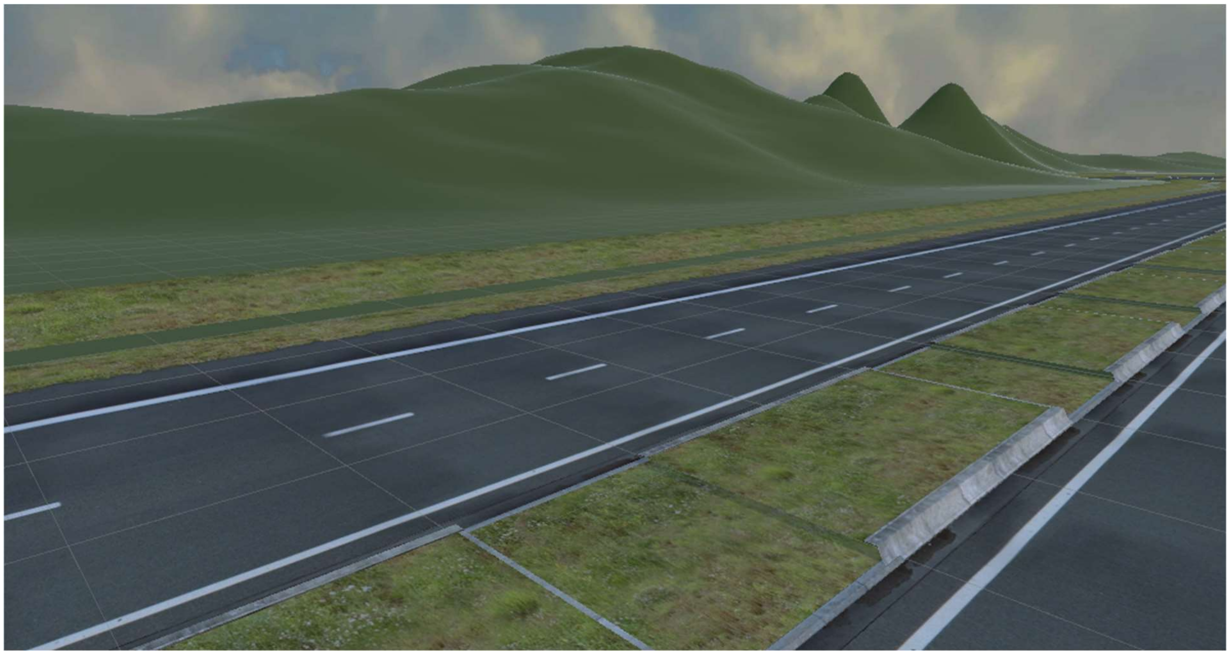

Figure 4.4 Highway scene

Figure 4.5 Industrial district scene

Figure 4.6 Residential district scene

4.4 Virtual environment scenario design

While the subject is moving through each block they experience various accident-prone scenarios. Described below are the accident-prone scenarios and their development process:

1.) Subject approaching a slower moving vehicle on a highway environment

2.) Automobile moving from left lane to right lane when the subject approaches close proximity to it. This scenario helps us to analyze the subject's reaction time

3.) A pedestrian crossing the road (Apart from the above-mentioned scenario, this pedestrian in a zebra-striped crosswalk in an urban environment was also implemented, which helps us to analyze the environmental observation capacity of the subject.)

The simulation of pedestrians crossing the road and computer-controlled automobiles on highways are implemented using the dynamic A* pathfinding algorithm. First, a set of waypoints were created in the environment along the route which the subject follows throughout the environment. The implementation of AI makes it much smoother and challenging for subjects going through the environment. Apart from these challenges, we also implemented a stationary highway police vehicle on the highway environment to study the subject's behavior towards police.

Figure 4.7 Highway patrol vehicle

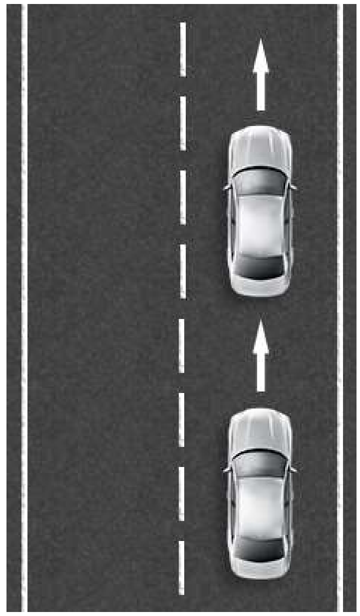

Figure 4.8 Subject approaching a slower moving vehicle on highway environment.

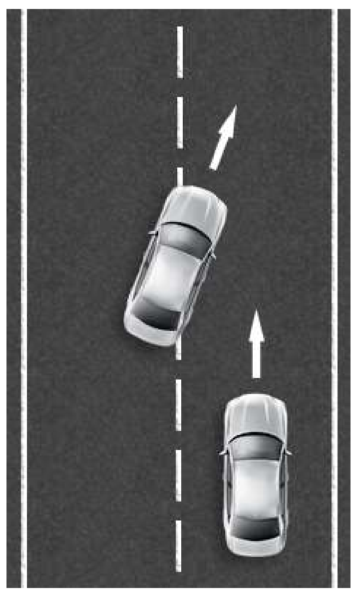

Figure 4.9 Automobile moving from left lane to right lane when the subject approaches close proximity to it.

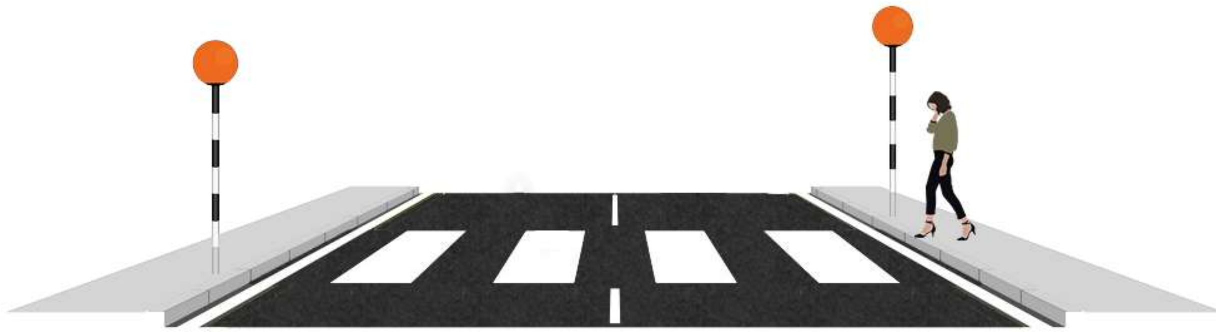

Figure 4.10 Pedestrians crossing road in urban environment.

4.5 Virtual Environment optimization

VR headsets consume a high rate of GPU and CPU cycles to render the virtual environment. To make sure subjects do not feel dizziness along with the study, an average of 60 frames per second is required as per the oculus developer manual. To achieve this framerate a number of tools and techniques are used to optimize the whole environment. Below mentioned are the techniques and optimization tools used to achieve this:

1.) A third-party extension called *mesh simplify*, available in the Unity store, was used to reduce polygon count on all 3-D models used in the environment.

2.) FXAA, an anti-aliasing technique, was used to render graphics with a smoother appearance while reducing load on CPU and GPU.

3.) To reduce the rendering of unnecessary objects in the virtual environment, a technique called occlusion culling was used (Occulusion Culling, 2019). This technique allows us to disable the rendering of objects which are not in the camera's view. This ultimately reduces CPU cycles and improves the frame rate.

4.) I limited texture sizes and combined meshes to improve performance. The level of detail has been implemented to render a low polygon count version of the object which is far from the camera view.

5.) Extensive and detailed lighting were implemented in the study environment to simulate sunset driving conditions. Lighting in unity consumes too much CPU and GPU resources. To reduce resource consumption, lighting was developed using built-in Unity baking techniques (Baked Lighting 2017).

4.6 Heart rate data collection

Subjects are equipped with an Empatica E4 wristband which is a class 2a medical device allowing us to obtain accurate and precise physiological data which is helpful to analyze subjects state while approaching complex scenarios in study virtual environment. Empatica E4 wristband allows us to record all real-time blood volume pulse (BVP) measurements from which the heart rate is derived, which is later used to correlate subjects heart rate to certain situations encountered in the virtual environment for this study.

Figure 4.11: Sample Empatica E4 session screenshot.

Chapter 5-Results

This chapter discusses key research questions for this study such as:

1. Identify differences in driving habits between a habituated driver and a new driver
2. Identify the cause of delayed response of the driver in the above-mentioned accident-prone scenarios
3. Identify the cause of delayed response of the driver in these scenarios.

To answer these questions, I analyzed experimental data to determine if there any factors may have influenced scores. Furthermore, I analyzed the correlation between survey questionnaire and heartbeat to analyze the change in subject's biological state.

5.1 Subjects

A total of 11 adults consisting of 9 males and 2 females (mean age = 22.4) with varying years of undergraduate and graduate education (mean =3.7). There were a total of 4 undergraduates and 8 graduate students in the entire study. Participants come from various education backgrounds spread out in a total of 3 colleges in this sample: Engineering (7), Architecture, Planning and Design (3), and Veterinary Medicine (1). None of the subjects were color blind and had no visual impairments and did not experience any dizziness during part 2 of the study. Out of 11 subjects, 10 stated that they have video game-playing experience (mean = 3.2).

After completing the part 2 of the study, subjects reported their mean comfort level was 3.3, indicating an average ease in navigating through the virtual environment.

Variable	Category	Total
Gender	Male Female Other	9 2 0
Age	Range of 18 to 26	Mean = 22.4
Type of student	Freshman Sophomore Junior Senior Graduate PhD	2 1 1 0 7 0
College	Engineering Architecture Veterinary medicine	7 3 1
Nationality	India Nepal Vietnam United States	8 1 1 1
Gaming Experience	On a scale of 1 to 5	Mean = 3.2
Comfort level	On a scale of 1 to 5	Mean = 3.3
Valid Driver's Licence	Yes No	10 1

Table 5.1 Initial questionnaire

Apart from this, subjects were asked a couple of post-survey questionnaire. Below is the representation of answers to the question in the form of pie charts.

Question 1. What do you think of the road size?

Option 1.) Realistic size option 2) Not of realistic size 3.) Maybe.

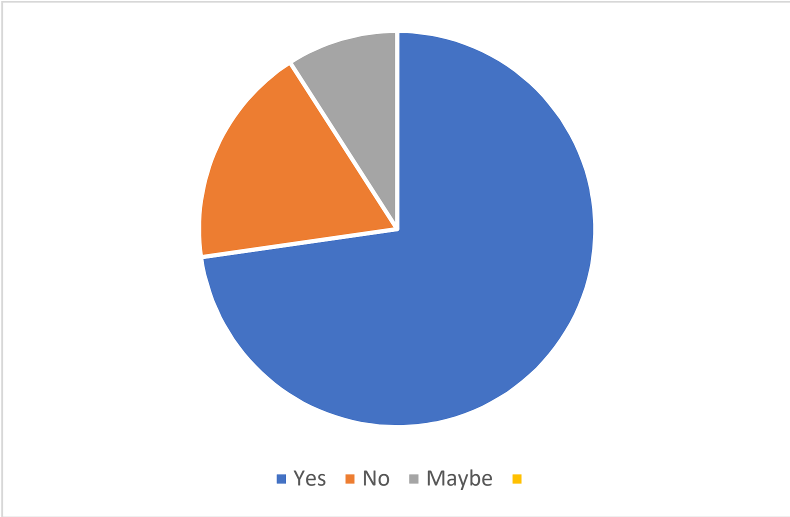

Figure 5.1 Feedback on road size

Question 2) Did you experience any simulation sickness or any other discomfort from performing this study?

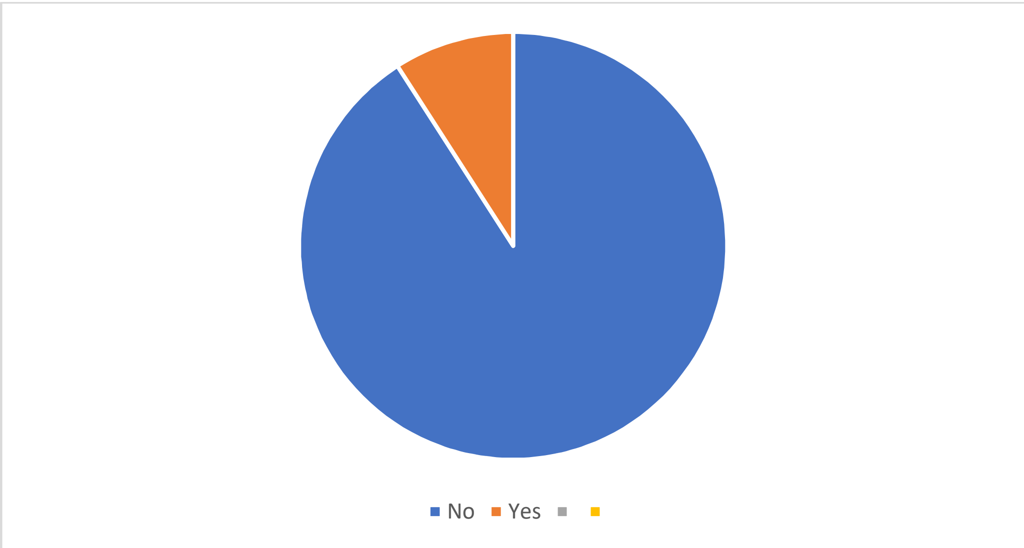

Figure 5.2 Feedback on simulation sickness

5.2 Correlation between demographics and driving performance

There is a high degree of observable variation among subjects in observing the environment, depending on the origin of the subjects. Subjects from India tend to perform poorly when compared to subjects belonging to other nationalities. Out of 11 subjects, 10 stop for a minimum of 2.4 seconds at the stop sign and proceed to the next path in urban environment.

Out of 11 subjects, 10 subjects paid keen attention and gave enough space to pedestrians for crossing the road in the urban environment and the change in the heartbeat was negligible.

Interestingly, 72% of the subjects drove above speed limits in the urban environment and 54% of the subjects decreased their speed by an average of 4 miles per hour than permitted limit when they observed a highway patrol car in the highway environment. Apart from this, 63% of the subjects had an increase in heart rate of an average of 3.5 beats per minute when they noticed a highway patrol vehicle. Also, there is an average increase of 8 beats per minute in heart rate in complex accident-prone situations. Subjects with valid driving license tend to perform better in these complex scenarios than subjects without a driver's license.

In the first accident-prone scenario, the average time for braking/slowing down for subjects ranged from 2.1 to 3.7 seconds. As they proceed further and face other accident-prone scenarios, their reaction time improved to a range of 1.7 to 2.5 seconds.

5.3 Supplemental Findings

A majority of the subjects tend to observe windmills, farms, and dense vegetation which is visually pleasing and also there is a decrease in heartrate while going through this path. In general, it appears that subjects were keeping an eye on the highway environment to get rid of boredom.

Out of 11 subjects, 3 subjects could not stay in their lane for around 40 – 45 % of the time in urban environments. This may be due to lack of experience driving in urban environments.

5.4 Limitations of Virtual Reality

A major obstacle for this research study was using a virtual reality headset as a 3-D immersive tool. Although, Virtual reality is an emerging and advancing technology for the past several years, there are still some major bottlenecks. For example, it is a painstaking process to optimize the virtual environment to achieve the desired frame rate. The development of applications for VR is expensive as it takes more man-hours to develop. Initially, for the desktop application we achieved an average frame rate of 75 – 80 fps, while the same environment deployed on the VR headset achieved a bare minimum of 55 to 60 fps. In order to achieve a minimum of 65 – 70 fps for VR headset, a lot of time has been spent on optimizing it. Due to lack of expertise and desktop hardware limitations, it took more hours in research and implementing solutions to improve frame rate. Also, the study environment is quite large and contained a lot of objects with a high number of vertices and triangles, which presented a technical challenge to consistently achieving the desired frame rate in a VR application. Most of the GPUs available today have a hard time rendering the virtual environment in high resolution in parallel with achieving good framerate. The majority of the people do not have hands-on experience with a fullfledged VR headset, this might result in simulation sickness and be considered while developing and designing a virtual environment for VR headsets.

Chapter 6-Conclusions

A virtual environment can be developed to be realistic enough for virtual reality headsets for driving simulators to conduct further research studies if there is a good equipment and available skill set at a reasonable cost. If a virtual reality environment can be designed to mimic real-life driving behavior then there might be additional new findings which might help in improving subjects driving skill. Virtual reality simulators can be a good way to practice driving but it currently is not a replacement to regular driving practice. Currently, virtual reality headsets are not perfect but can be used to study and explore other implementation possibilities in different domains. Based on the results of this study, I found evidence to support the premise that a full-scale virtual reality driving simulator with complex scenarios and environments can be beneficial for driving schools, individual training, training EMS, police, and firefighter personnel.

Chapter 7-Future Work

Virtual reality headsets are a promising emerging and advancing technology which has multiple applications in medical, entertainment, education, and simulation domains. Many people do not completely understand the purpose and the true potential of virtual reality headsets. For future work, I think that the most important improvement to be made in VR headsets is to improve high-resolution 3-D object projection to improve the immersive experience which might result in lower VR sickness. Also, this study can be extended to study the response time and behavior of drivers in fully autonomous vehicles in complex scenarios, and also to study their behavior when equipped with assistive technologies for driving such as blind-spot monitoring, emergency braking, and other active and partial driving aids. Further extensions of this work, such as more gamified version of the virtual environment, can be developed with more expertise in skills. Because VR is a continuing area of rapid technological advancement, and there is increased demand due to this advancement and the resulting economy of scale in fielded products, there will continue to be new ways to implement systems to explore these research problems in various application domains.

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