博士論文 (Ph.D. THESIS)

自律走行車での 3D AR エンターテインメント時のドライバーの危険状況に対する反応の評価

Evaluation of driver’s reaction to hazardous conditions during 3D AR entertainment in autonomous vehicles

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Ph.D. THESIS

Evaluation of driver's reaction to hazardous conditions during 3D AR entertainment in autonomous vehicles

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Dedication

This work is dedicated to the entire Muguro's family who have been a constant source of inspiration and love. To my late brother, **Kinuthia Muguro**, road accident separated us, but you live on in our memories.

Acknowledgment

My deepest gratitude is to the Lord God Almighty, author and sustainer of life, for the strength and unfailing grace in my entire life; He never gives up on me!

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Abstract

The transportation industry is one of the essential enablers of the 21st century. To date, multiple modes of transportation have been explored, ranging from commercial drones, intelligent mobility vehicles, autonomous vehicles (AV), self-navigating robot taxis, ships, airlines, among others. Despite its importance, transportation is faced with a constantly shifting set of problems. According to a road safety report by World Health Organization, fatalities emanating from road traffic accidents (RTAs) have increased to 1.3 million per year. Vehicle automation has been floated as a strategy to combat the many challenges facing transport industry. With the introduction of the autonomous vehicle (AV), road safety, pollution, and accessibility to services for all will be greatly improved. In addition, commute time will be redefined as drivers will necessarily be passengers, freeing the driving time for a more productive task.

According to the society of automotive engineering (SAE) standards, automation is classified into six levels, ranging from level 0, with no automation, to level 5 with full automation. A paradigm shift towards road monitoring is in level 3 where the role of driver changes to a supervisor. The transitory phase, level 3 and 4 are critical in safety as they as feature a situation whereby the AVs share roads with human drivers. Additionally, drivers in this level will be required to assume control in cases where the autonomous system encounters uncertainties. As such, the road user will be required to be monitoring the road even if they are not actively intervening. Research has shown that automation will lead to more fatigue and loss of vigilance due to inactivity. To ensure safety, the autonomous system will be mandated with driver monitoring and or vigilance enhancement methods before the user can take over control.

In this work, we posit that entertainment will play a major role in maintaining vigilance of the drivers and as such, the ideal activity during transit. For safety, we explore ways of integrating entertainment with road monitoring using 3DAR that meshes road conditions with entertainment. As such, the target is to evaluate driver's reaction to hazardous conditions during 3DAR entertainment in autonomous vehicles. To this end, three experiments were conducted. In the first and second experiment, hazard reaction is investigated in active and passive (driving) scene. Additionally, we investigated how secondary (entertainment) tasks impact hazard recognition. In the last experiment, we introduced entertainment tasks in an actual moving car integrating car dynamics and somatosensory information to the user to achieve an immersive augmented reality. The setup was used to investigate hazard response, posture corrections and engagement levels with different tasks.

The work utilized custom-made scenes designed using Unity 3D software and FOVE 3DVR head mounted display to realize the proposed system. For evaluation, physiological signals were used as opposed to conventional systems that rely on subjective methods like questionnaire. As such, surface electromyogram (EMG), electrodermal activity, eye gaze and pupillary responses were employed to give insight into the driver state.

In the first experiment, an event/scene that the driver considered hazardous was marked with increased EMG response distinct from baseline. The results suggested the validity of using EMG response in an actual driving environment to characterize error or hazards. The average reaction time in active driver scene was around 0.5 seconds. Experiment two investigated the impairment of threat recognition time using popup objects while engaging in a secondary task (No-task, AR-Video, and AR-Game tasks). There were no significant impacts on the threat recognition time (Less than 1 sec. difference between the means of the game task to no task). Game scoring followed three profiles/phases: learning, saturation, and decline profile. From these, it was possible to quantify/infer drivers' engagement.

As an extension to the second, experiment three involved a driving simulation with four activities: no-task, Game-task, Video-task, and Mixed-task, played in a moving car environment. The experiment was conducted in a real car with a FOVE VR headset on the perimeter track of the Gifu University campus. From hazard recognition time, significant difference between tasks was found using one-way ANOVA ($F(3,231) = 2.75$, $p = .0437$) with game and mixed task reaction time being significantly different ($p = .0126$ and $p = .016$). Engagement inferred from pupil size, and skin conductance indicated an increased or sustained effect compared with baseline. Pupil size increased with engagement tasks as

indicated by means; no task (mean = 0.661), Game-task (mean = 0.717), Video-task (mean = 0.78), and Mixed-task (mean = 0.846). Similarly, EDA responses was least in no task and highest in mixed task as indicated by means; No task (mean = 0.53), Game-task (mean = 0.648), Video-task (mean = 0.61), Mixed-task (mean = 0.66). The result also reported a 10-fold improvement in postural adjustments.

In conclusion, the proposed model sought to ensure a safe transition from autonomous system to human drive through tasks that meshes hazard monitoring and entertainment. The system with entertaining tasks (games and video tasks) managed to engage the users in an autonomous system compared to no task with no adverse effects on hazard recognition. In addition, the proposal was found to be 10 times more performant in posture correction compared to a no task. The system proposes a prospective market in an in-car entertainment system that adds value to drive experience. As a limitation, the experiments relied on a 3D-AR game prototype to investigate future dynamics in actual AVs. Further tests and investigations are still needed to fully understand the dynamics of experiences targeting entertainment and other activities like office work, reading, and writing.

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CHAPTER I: INTRODUCTION

1. INTRODUCTION

1.1 Background

The transportation industry is one of the essential enablers of the 21st century. A country's productivity depends on the efficiency of its transport system and networks to move labor, consumers, and freight as per the demands. At present, mobility is a key consideration for advancement in an all-inclusive society. To this end, multiple modes of transportation have been explored, ranging from commercial drones for package delivery, smart mobility vehicles, autonomous cars, self-navigating robot taxis, self-navigating ships, and airlines, among others. The focus of all such efforts is to improve the quality of life, enhance service delivery, safety, reduce running costs, conservation of natural resources, and reduce carbon footprint through renewable energy.

Despite its importance, transportation is faced with a constantly changing set of problems with the consecutive upgrade. The most significant problem plaguing the transportation industry is traffic accidents. Road traffic accident (RTA) results when a vehicle, for whatever reason, collides with another vehicle, pedestrian, animal, road debris, road infrastructure, or other stationary obstruction such as trees, pole, or building. RTA often results in death, injury, disability, and property damage. More often, RTAs impose heavy financial burdens on both society and the individuals involved. In case of death or fatalities in an accident, this is referred to as Road Traffic Death (RTD) and is related to death within 30 days of a traffic incidence [1], [2]. On a general sense, safety on the roads is always aimed at reducing RTA incidences.

Several research agencies and regulatory bodies are working towards a safer, inclusive society in transport systems. Amongst such is the transportation research board that identified technology, population shifts and trends, sustainability of transport mode, equity, energy conservation, safety, and public health, performance etc., as some of the critical points to consider presently and for the future.

Population shifts and trends are important issues in transportation that affect efficiency and safety a great deal. Transportation needs to follow population trends. Similarly, the need for a sustainable transport network cannot be over-emphasized. Urbanization brings high motorization that leads to traffic congestion and pollution, all of which are significant problems. In the US alone, it is estimated that highway congestion costs the nation approximately $300 billion annually due to delays and wasted time. Expanding road infrastructure in urban areas is costly and time-consuming.

Another issue crosslinked with transportation touches on the aged, disabled, and ill persons of the society. The World Health Organization (WHO) estimates at least 15% of the world population to be disabled. Access to health services plays a critical role in the lives of such individuals. Access to working conditions and usage of current means of transportation is also a challenge. A recent phenomenon in developed countries is an increase in the aged in society. According to recent statistics, the percentage of the population aged 65 years old and over in Japan was 26.6%, which is the highest globally. With such trends, transport needs will need to be updated to accommodate the diversity of services.

Therefore, the question is how we can serve the growing transport demand in a financially, socially, and environmentally acceptable way. To address this issue, several proposals have been adopted and or explored. One such is the use of electric cars applying renewable energy sources and hybrid, zero-emissions vehicles. Electric vehicles created a demand of electricity that can be fulfilled using renewable energy [3]. This comes with the benefit of reducing CO_2 emissions, electric mobility, and efficiency general car efficiency gains.

Another strategy has to do with automation in the transportation industry. The reach of automation will vary from the digitization of travel routes and plans using smart devices to automation of travel vehicles. Digitization of all aspects of transport introduces connected and automated vehicles which is likely to proliferate in the coming decade. Together with shared and electric mobility, these changes will reshape the planning, operation, and regulation of transport systems.

The research work focuses on autonomous vehicle (AVs) as a potent solution to multifaceted challenges faced in the transport sector. In a nutshell, AVs are expected to reduce RTAs, decreased vehicle emissions and carbon footprint through electric and hybrid vehicles as well as optimal routing, improve safety for pedestrians and cyclists, enhanced mobility for special care groups (elderly and disabled), and the freeing up of parking areas for other uses. On the other hand, the psychological and behavioral changes associated with AVs have not been fully exhausted.

1.2 Challenges

1.2.1 Driver and traffic safety

WHO report has identified RTDs as the leading cause of death for people groups between 5-29 years of age. According to the report regarding road safety in 2018 by WHO, fatalities emanating from RTAs have increased to 1.3 million per year globally [4]. A survey by National Motor Vehicle Crash Causation Survey, conducted between 2005-2007, collected on-scene information about the events and associated factors leading up to a road traffic accident. Different facets of crash were investigated in the study, namely the precrash movement, critical pre-crash event, critical reason, and the associated factors. In the study, their main causative agents are identified as Driver, Vehicle, and Environment. The critical reason is the immediate reason for the crash. Critical reasoning is applied to point to either the driver, vehicle, or environment. From the study, driver as a causative reason was estimated to be 94 percent (±2.2%) of the total crashes. Vehicle and environment as a cause was estimated at 2 percent (±0.7%) and 2 percent (±1.3%) of the crashes, respectively. From this, the driver is a critical part of road traffic experience and safety worth considering further.

Table 1-1 gives detailed information on driver-related causes that are broadly classified into recognition errors, decision errors, performance errors, and non-performance errors. From the table, recognition error, which entails driver’s inattention, internal and external distractions, inadequate surveillance, and road monitoring, is the highest cause of incidences at 41 percent. Decision errors: speeding, improper curving, swerving, false assumption of others' actions, illegal maneuver, and misjudgment of the gap, amongst others, was estimated at 33 %. Performance errors: overcompensation, poor directional control, was approximated at 11 percent. Non-performance error which majorly features fatigue and sleeping on the wheel accounted for 7 percent.

In the advent of AV, human factors are expected to reduce however, according to [5], safety of AV will continue being bottlenecked by the presence of human drivers and motorist when the two share roadways. As such, safety should be considered, albeit with new light of automation.

Table 1-1: Driver-Related Critical Reasons

Critical Reason	**Estimates**	
	Percentages*	std
Recognition Error	41%	±2.2%
Decision Error	33%	±3.7%
Performance Error	11%	±2.7%
Non-Performance Error (sleep, etc.)	7%	±1.0%
Others	8%	±1.9%

*Percentages are based on unrounded estimated frequencies (Data Source: NMVCCS 2005–2007)

1.2.2. Shifting control from autonomous to driving mode

In the advent of the 21st century, several technological advancements have been performed to alleviate traffic accidents. At present, driver assistance and other technologies have been commercially released. The modern car incorporates driver assistance layers generally referred to as Driver Assistance Systems (DAS) and Advanced DAS (ADAS), depending on the sensors in use. Earlier models of ADAS focused on stability control, anti-lock brakes, blind spot information systems, lane departure warning, adaptive cruise control, and traction control, among others. The recent updates take into consideration the driver as a central key player. Assistance includes a human-machine interface, collision warnings, driver monitoring systems, among others. At present, the car can assume lateral and horizontal controls (braking and steering) in the face of an accident. A safe human-machine interaction is achieved through these systems, which has advertently increased car and road safety.

The reach and effects can be explained by looking at levels of automation as determined by the Society of Automotive Engineering (SAE) standard shown in Table 1-2 [6]. In level 0, the driver oversees all aspects of car operations. At this level, environment monitoring, and controls are purely left to a human driver. Level 1, on the other hand, incorporates driver-assistive technologies. Emergency braking, lane assistance, and stability control can be performed by the car at this level, but the driver is still mandated to monitor.

In level 2, partial automation, the system can perform lateral and longitudinal controls (accelerating/braking and steering operations) based on preset conditions and information gathered from external sensors. Cars in this level incorporate a pool of sensors ranging from cameras, environment sensors, inertial motion sensors, among others, to understand the environment and acts however the driver performs the actual environment monitoring.

Table 1-2: SAE international automation levels

Level	**Name**	**Definition**	**Controls (Lateral & Longitudinal)**	**Environment Monitoring**	**Fallback System**
0	No automation	Full-time performance by the human driver of all tasks	Human Driver	Human Driver	
1	Driver Assistance	Selective execution of tasks by an assistance system like emergency braking. The human driver handles all other driving tasks	Human and System (Assistive technology)	Human Driver	Human Driver

2	Partial Automation	Assistance of both steering acceleration/decelerations. The human driver handles all other driving tasks	System	Human Driver	Human Driver
3	Conditional Automation	Automated driving with the human driver responding to a take-over request.	System	System	Human Driver
4	High Automation	Automated driving even if a human driver does not respond to a request to intervene	System	System	System/Human
5	Full Automation	Automated driving task under all conditions that can be managed by a human driver	System	System	System

In level 3, conditional automation, the car can assume all aspects of control, and the human driver acts as a fallback system. The car will perform all operations and relinquish controls to the driver in case of uncertainties. At this level, the role of the driver, and thereby, driving behavior is drastically altered, to surveillance only. In level 4, high automation, all operations of the car can be performed by the system. At this level, if the fallback human driver does not take over, the system can safely steer the vehicle away from the road. Finally, in level 5, full autonomy is achieved where the driver becomes a passenger.

Of particular interest in this study is the influence of Level 3 and 4 to driver. From the levels, users will be required to assume control in case of uncertainties on the road. For this to happen, the driver ought to be in the control loop. According to [6], a fallback-ready user should always be receptive to requests or eminent vehicle system failure whether a takeover request is issued or not. However, owing to reduced engagement and monotonous driving, fatigue is expected to set in quickly in AVs than in manual driving. The reduced vigilance will be a potential challenge that need to be addressed as it can invalidate all the good accrued. With the present level 2 and 3 autonomous vehicles, road monitoring and not driving is counter-intuitive and impractical though desirable. In reports on AVs, fatal crashes have been reported where the safety-driver was inattentive or was engaged in secondary tasks [7].

Figure 1-1 shows the results of a survey on preferred time utilization in an AV. According to the survey, the top five tasks the users will engaged in are road monitoring, communication, sleeping, videos and games, work [8]. In Asia, road monitoring accounted for 26.7% of the time, social engagements (calls and communication) take up 25%, sleep/napping takes 16.7%, videos and games takes 8%, work takes 8% while the rest of the tasks account for 9% of the total travel time.

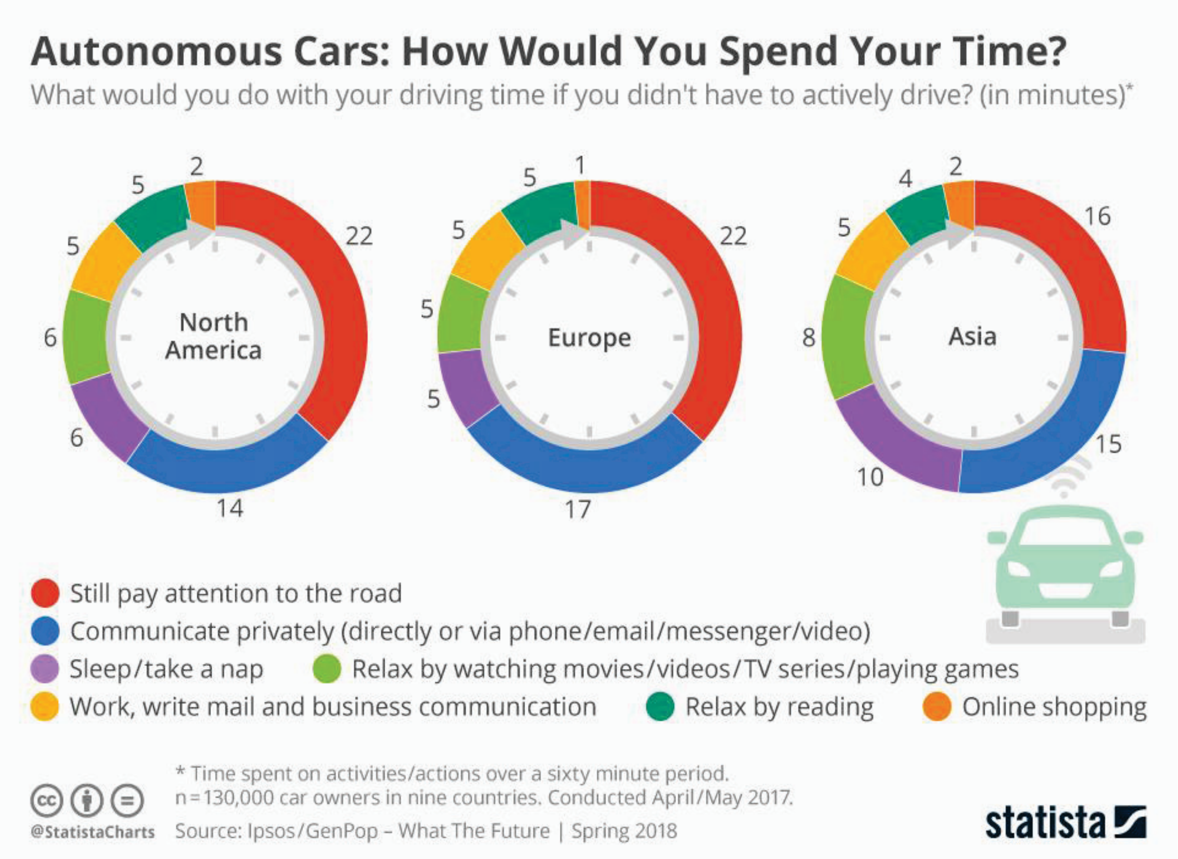


Figure 1-1 Survey of time usage in autonomous vehicles [8]

Road monitoring would be indicative of mistrust of the AV users and as such the high urge to still monitor the road for threats. On the other hand, the need for entertainment and relaxation is significant taking more than half of the remaining time. There is a prospective market for a system that integrates safety, indicated by road monitoring, and entertainment to the modern cars to increase productivity in in-car experience. One way of achieving this is integrating preferred user activities to road monitoring in a synthetic environment (virtual/augmented reality (AR/VR)).

This work explores the use of 3DAR contents to maintain the vigilance of driver. The system integrates driver monitoring with a desirable task (game or video) in VR during an actual car movement. The study evaluated various engagement tasks in 3DVR contents to determine the readiness of assuming control indicated by reaction/recognition time of hazards along the drive path.

1.3 Objectives

From the proceeding, the research work explores driver monitoring methodologies that are feasible in ensuring traffic safety both at present and the future where autonomous vehicles are fully operational.

1.3.1 Main Objective

Evaluation of driver reaction to hazardous conditions during 3D AR entertainment in autonomous vehicles.

1.3.2 Specific objectives

The specific objectives are as follows:

I. Evaluate physiological measures of driver monitoring during a simulated active driving with head on collision popup traffic
II. Investigate the effects of gaming using hazard recognition time in a simulated 3DVR scene that merges game and road monitoring task on an office setup
III. Explore different 3DAR content on an actual moving car to investigate hazard response, posture corrections and engagement levels with different tasks.

1.4 Outline of the Thesis

The rest of the thesis is organized as follows; a detailed literature review of the state-of-the-art practices and research is presented in chapter 2. Materials and methods are discussed in chapter 3. Chapter 4 discusses design of hazard response during an active driving simulation experiment. Chapter 5 discusses design and considerations of road monitoring using gaming and gamified tasks. Chapter 6 discusses the prospect of in-car entertainment systems using VR and AR modalities to enhance productivity during autonomous driving and chapter 7 draws the conclusion and recommendations from the study.

CHAPTER II: LITERATURE REVIEW

2. LITERATURE REVIEW

This section reviews relevant studies road towards safety, identifying the bottlenecks that exists and the solutions so employed. Further, trends in driver monitoring and productivity enhancement methods are reviewed.

2.1 Role of Driver in Accident Occurrence

Accident prevention studies have been a topic of interest over decades since the invention of automobiles. From preceding sections, the role of driver has been highlighted both in literature and conducted case studies. In a feature article [9], Japan highlights the need to incorporate driver analysis to reduce RTAs. According to the report, more than 60% road accidents occur around the same intersections, which the report terms as hazardous spots. As of 2016, the country had more than 3000 spots that fit this criterion. One of the criteria for determining a hazardous spot has been the occurrence of multiple accidents around the same spot. The report describes the measures the stakeholders are employing to reduce RTAs. They recommend the use of finely tuned measures of analyzing traffic accident and clustering the occurrence of such with big data mining. One of the future goals of the study is to incorporate driver behavior like harsh braking, over speeding sections, etc. and use big data analysis to identify potential hazardous spots.

Data analysis for accident comprehension was performed in Kenyan road accidents study in [10]. From the study, between the year 2015 and 2020, accident fatalities have increased by 26.3%, injuries 46.5% and incidences involving motorcycles have had over 500% increase. Figure 2-1 shows the trend of injured pillion passengers (motorcycle passengers) between 2015 and 2020. From the figure, injuries had increased by over 700% by 2020 and is expected to exceed 1000% by 2021.

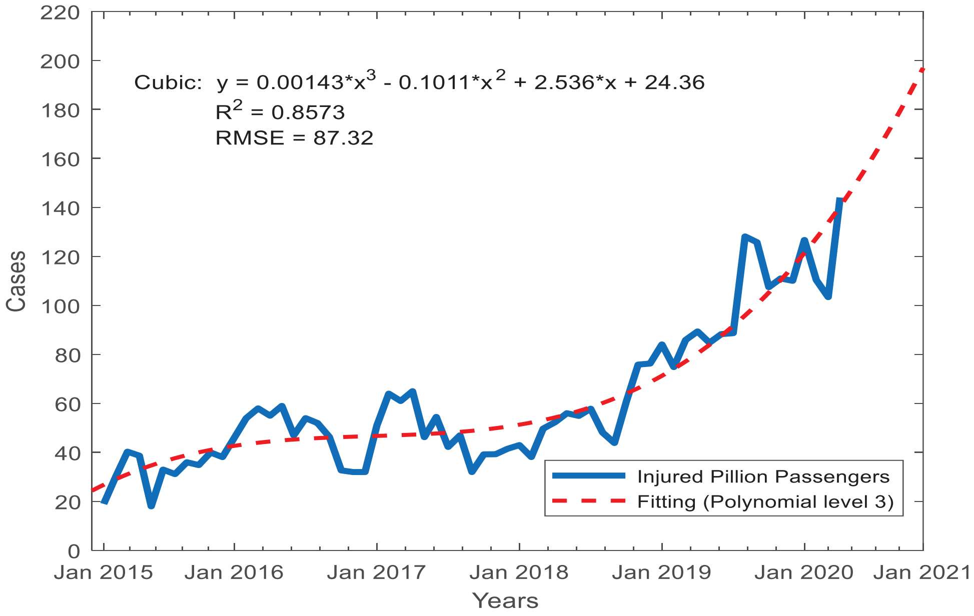


Figure 2-1 Motorcycle injured passenger trends in Kenya between 2015-2020

The study involved text mining of public accident records (eye-witness brief descriptions of the accident) to extract meaningful categorization of cause of accidents. In this case, Latent Dirichlet allocation (LDA) model for text mining. LDA is an unsupervised machine learning algorithm that uncover categories (topics) in texts. Figure 2-2 gives the general workflow of LDA algorithm [11].

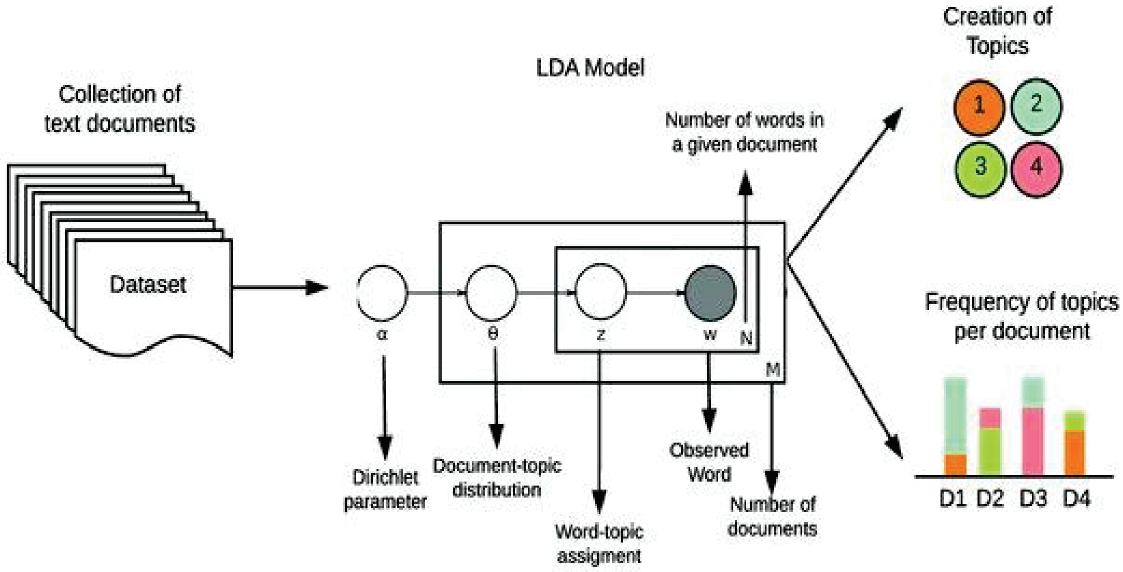


Figure 2-2 Latent Dirichlet allocation (LDA) workflow [11]

In this case, each column entry in the "brief accident detail" of Table 2-1 is considered as input dataset to the LDA workflow. LDA takes in a collection of *D* documents with a topic mixtures $\theta_1, \ldots, \theta_D$, contained in *K* topics. Each topic is characterized by word probabilities $\varphi_1, \ldots, \varphi_K$. The assumption made is that the topic mixtures and the words in the topics follow a Dirichlet distribution with concentration parameters α [12]. The generative process $p(\theta, z, w|\alpha, \varphi)$ of a document with words $w_1,\ldots,w_N$, topic mixture θ, and with topic indices $z_1,\ldots,z_N$ is given by

$$p(\theta, z, w|\alpha, \varphi) = p(\theta|\alpha) \prod_{n=1}^{N} p(z_n|\theta)\, p(w_n|z_n, \varphi) \qquad (1)$$

Equation 1 above is further integrated to give the probability of marginal distribution $p(w|\alpha, \varphi)$ of document w as shown in equation (2). The output of LDA is topic distribution probabilities per document as shown in Figure 2-2.

$$p(w|\alpha, \varphi) = \int_{\theta} p(\theta|\alpha) \prod_{n=1}^{N} \sum_{z_n} p(z_n|\theta) p(w_n|z_n, \varphi)\, p(w_n|z_n, \varphi)\ d\theta \qquad (2)$$

In the study, the results of LDA with four selected topics is as shown in Figure 2-3 as Wordcount clouds. Wordcount shows the frequent words in bold colored letters and less frequent are faded out. From the figure, four topics are apparent; hit/run, head/collision, lost/control and victim/knocked/down.

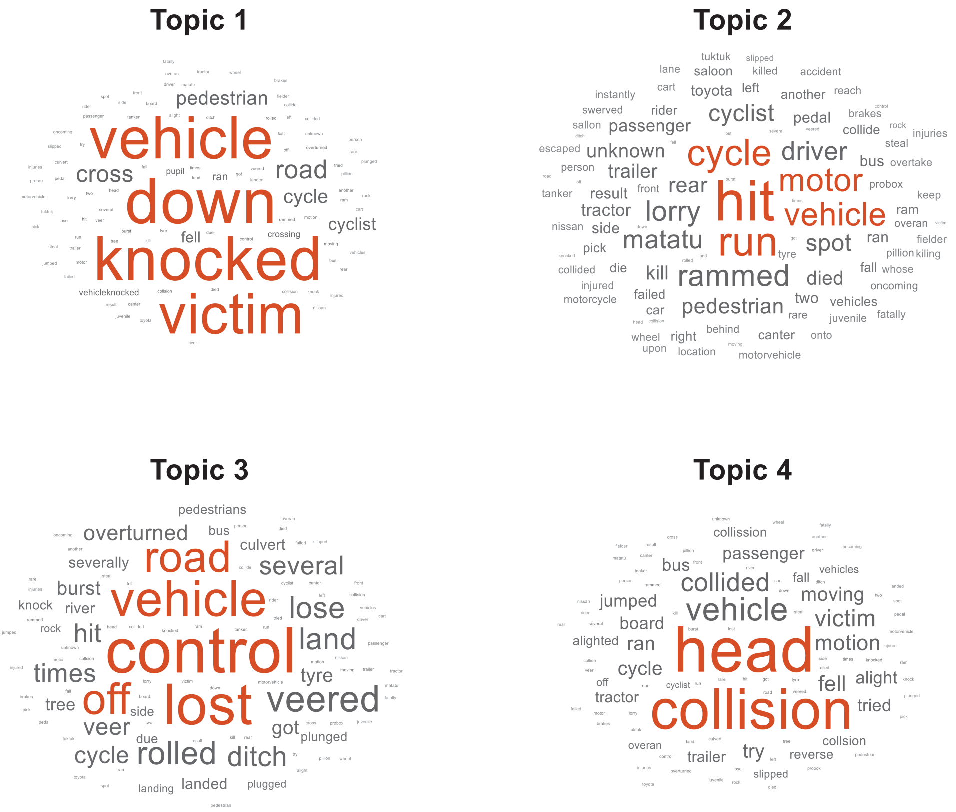


Figure 2-3 Accident cause in the country as classified by machine learning model

The study identified four leading categorization of accident causes in the country as, knocking down victim (run over victim), hit-and-run, vehicle losing control and head on collision. The overall probabilities are given as 0.3534, 0.2773, 0.1803 and 0.1889 from topic 1 to 4, respectively. This translates to a 35.34% prevalence in running over victim followed by 27.73% for hit and run, 18.03% for lost control and 18.89% for head-on collision. From the categories, it is clear how the vulnerable groups (pedestrians motorcycle users) are most affected. In knocked down victims and hit and run categories, the target victims are the vulnerable road users. This is in agreement reported literature focusing on susceptible road-users [13] [1].

The four identified categories are shedding more light on the general cause of fatalities. Arguably, the driver errors and/or negligence is significant in all the four categories. Particularly, the leading cause of fatality, knocked down victim, points to the modality of driving and road safety standards observed by the country. Speeding, careless driving, drunk driving and other detrimental driver behaviors can be linked with each of this category.

In summary, driver errors are a big determiner of the outcome of accident occurrence as well as the severity. Driver monitoring then, ought to be seriously considered to improve safety and wellbeing in transport sector. In the rise of AVs, the roads will be shared with human drivers until such a time when everything is fully automated. As such, safety concerns emanating from drivers will need be looked at. On the other hand, when AVs are in operation, the human will act as a supervisor and or fallback control. Thereby making drive monitoring a much more needed undertaking.

2.2 Driver Monitoring and Takeover Requests in Autonomous Systems

Driver monitoring systems have been applied in varying capacities in the modern automobiles. Driver monitoring systems or Driver Attention Monitor was first introduced by Toyota in 2006. The System features a charge-coupled device (CCD) camera on the steering or dashboard that tracks the face with infrared LED detectors. If the driver is inattentive to road conditions and a hazard situation is detected, the system warns the driver using haptic and auditory signals. Popularly detected state using these methods are inattention, distraction, and drowsiness. In the advent of autonomous vehicle, monitoring distraction will have to be redefined to fit the new role of supervision.

Table 2-1 Sample Fatal report from NTSA (report data as at 14th Feb 2016 data snippet)

NATIONAL TRANSPORT AND SAFETY AUTHORITY

FATAL REPORT AS AT 14TH FEBRURARY 2016

S/N	TIME 24HR	BASE	COUNTY	ROAD	PLACE	MV INVOLVED	BRIEF ACCIDENT DETAILS	NAME OF VICTIM	GENDER	AGE	CAUSE CODE	VICTIM	No
1	545	MTWAPA	KILIFI	MOMBASA KILIFI	MSAMBARAUNI	KBZ 884F ISUZU LORRY,KTWA 833W TUK TUK	HEAD ON COLLISION	UNKNOWN	M	32	26	DRIVER	1
2	300	INDO AREA	NAIROBI	MOMBASA	CAPITAL CENTRE	KYQ 080 VAN	THE VEHICLE KNOCKED DOWN THE VICTIM WHILE CROSSING THE ROAD	UNKNOWN	M	43	63	PEDESTRIAN	1
3	300	KAREN	NAIROBI	NGONG ROAD	MIOTONI	KBS 001C M/BENZ,KMDD 597S YAMAHA	THE VEHICLE HIT THE MOTOR CYCLIST	G** WALUMBO	M	46	7	M/CYCLIST	1
4	620	DIANI	KWALE	BEACH ROAD	ASILIA COMPLEX	KBT 998R T/BUS	THE VEHICLE KNOCKED DOWN THE VICTIM WHILE CROSSING THE ROAD	M** ATIENO	F	26	63	PEDESTRIAN	1
5	UNKNOWN	CHANGAMWE	MOMBASA	MIRITINI	MAGANDA	KBK 897Q	THE VEHICLE KNOCKED DOWN THE VICTIM WHILE CROSSING THE ROAD	UNKNOWN	F	6	68	PEDESTRIAN	1

According to the SAE standard, as from level 3, the driver is not mandated with constant monitoring of the driving environment but will need to resume control in case of unforeseen encounters. The system issues a take-over request when it encounters uncertainties (e.g., missing road markings, foggy weather). To this end, for automation levels, the driver/user of AV would be free to engage with secondary tasks (non-driving related tasks) during transit.

2.2.1 Non-driving related tasks (NDRT)

In a conventional vehicle system, NDRT encompasses all tasks (secondary tasks) engaged by the driver while driving [14]. This includes use of handheld devices, operating in-car systems, communicating with passengers or on calls, etc. Up to date, research and policies have been focused on dissuading drivers from engagement in secondary distractive task(s) owing to the threat these activities pose both to the driver and other motorists [15]. Research have been conducted to understand driver behavior in an NDRT environment for AV. A paper by [14] investigated the effects of NDRT to quality of take-over in varying traffic situations. The authors employed two tasks: visual surrogate reference task as a representative of eyes-off-road and n-back test as a mind-off-road engagement. There was no reported significant difference between the two types of distraction. A paper [16], evaluated the influence of driver in news and email reading, watching a video clip and engaging with tablet. Another paper [17] used video and a tablet gaming NDRT to evaluate driving behavior in a critical conditional take-over. The authors concluded that there was no influence of NDRT on reaction time. Authors in [18] found that engaging in distractions have the potential to reduce up to 27% drowsy tendencies in automated drive.

2.2.2 Driving related tasks (DRT)

Since AV will eliminate the need for active driving inputs as well as constant monitoring of the road, activities performed by the driver will not be categorized as distraction [18]. This is the paradigm shift modulated by automation, where distraction is desirable in a car environment i.e., DRT concept. As noted by the report (Dingus et al., 2006), DRT can be a potential source of hazard in conventional driving. However, as AV takes full shape, driving will be the distraction as roles get reversed. DRT in AV is redefined to migrate from the conventional potentially hazardous of a task to a positive engagement that seeks to enhance the driving experience. In this case, DRTs seek to aid/promote overall improvement in the driving experience. To this end, activities that promote proper sitting posture, adherence to proper hands-on-steering wheel, road monitoring, leg-pedal positioning among others would be considered as DRT. Intuitively, tasks that promotes road monitoring and hands-on-steering wheel would improve the quality of take over and help in promoting situational awareness and vigilance [20]–[22].

As such, the design of in-car VR or tasks can supplement this by offering contextually relevant information alongside the engagement modality [23], [24][25]–[27]. In this paradigm shift, distraction is desirable in a car environment i.e., driving related task (DRT). In this case, a strong appeal is to keep the users vigilant by activities/engagement that helps in indirect road monitoring as a security measure. From [6], a fallback-ready user should be receptive to requests or eminent vehicle system failure whether a takeover request is issued or not. According to a Waymo® report on public road safety performance data, the group reported 47 collision and minor contacts for 2019/2020 operations [5]. Besides this, news about the fatal accidents involving ‘self-driving’ cars still loom with the usual human fault in the fallback-ready user as is the case in [7], [28]. From the above, the limitations of the AV will continue being bottlenecked towards safety as long as AV share roadways with human drivers, way past the fully autonomous levels are arrived at [5], [29]. What needs to be addressed is a way to optimize safety by ensuring direct or indirect road monitoring of fallback users for readiness to take-over control.

Research targeting take-over request focuses on parameters like time to hands on steering, time to first reaction, time to eyes on the road, among others. In the present study, we consider this as reaction time which is universally accepted measure. This is the time taken for the driver to notice and initiate an action in a driving environment. Authors in [30] compared the response time of novice vs experienced drivers and concluded that there was no significant difference. We considered hazard response as the process of responding to perceived impeding threatening situation in the road that if left alone would lead to a traffic accident. We considered anticipation and reactionary response to driving events. Hazard perception in [30] is associated with anticipation, surprise, and complexity. Anticipation is the notion that the driver recognized an impeding undesirable event and takes precautionary measures.

With the current technological advancement, the driver can be engaged in a myriad of activities each soliciting the driver to different states. To reduce chances of failure in take-over, authors in [18] argue that AV will necessarily be tasked with monitoring the driver to assess the readiness to take-over control. One way of achieving that is monitoring the task the driver is engaged in. Authors in [31] argue that engagement with gamification in driving can reduce the risks associated with boredom and reduced vigilance. With this in mind, we have conceptualized driver engagement model based on the content source and management routines as shown in table 2-2.

Table 2-2 Driver engagement model

State	*Engagement status*	*Description*	*Challenges*
0	Active state	Road monitoring with no distractions	*Monotony* *Hard to maintain*
1	AV Managed Tasks	The driver engages with tasks like watching movies, games, etc. that are managed by AV system. This gives the advantage of ease of passing relevant drive information as well as indirect driver monitoring system. There are no such systems at present.	*In-existent in the market (Proposed system)*
2	External Devices Tasks	The driver engages with tasks with connected devices (smartphones, tablets etc.) This allows for active sharing of relevant information.	*Interlinking between external device and AV*
3	Passive State	The driver engages with tasks unrecognized to the system. This covers all tasks including unconnected devices and naps	*No feedback*

The desirable state is for the driver to be in non-distracted and actively monitoring the road. Since this state is hard to maintain, we conceptualize three other states. In the primary level, the NDRT content is managed by the vehicles (AV), i.e., start, stop, pauses, interrupts, and other probes are used to focus driver's attention. The foreseeable advantage of this is that information delivery can be optimized to integrate with the current road conditions. In the secondary level, external personal devices are linked to the system such that interrupts can be relied with pertinent information as opposed to the driver having to build his/her own situation awareness. Several authors [16], [21], [32] have investigated NDRT in this level. The third state is the passive one, with use of devices that are unconnected or tasks that are blind to the system like deliberate nap. A passive level will be the ultimate experience of an AV in level 4 and above.

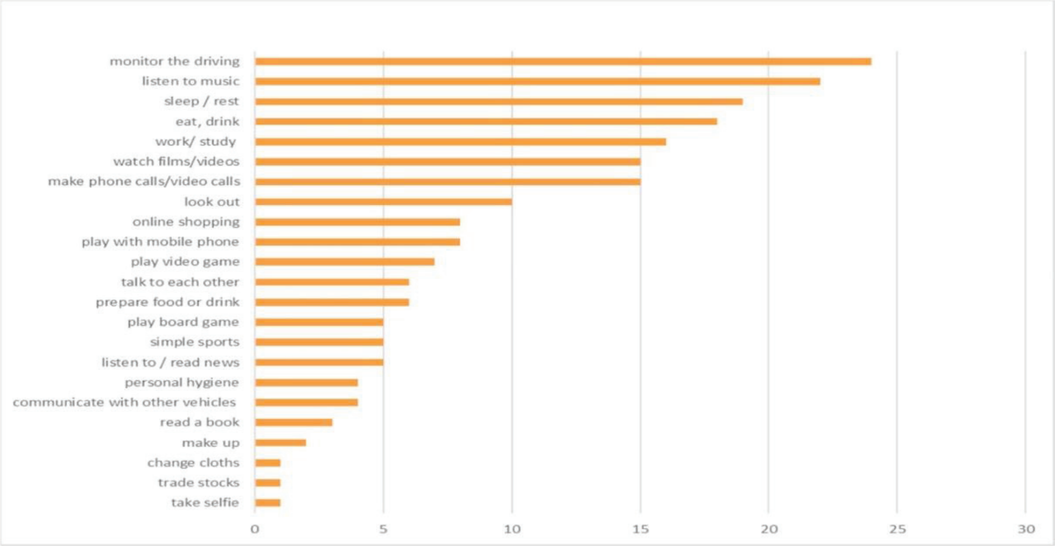


Figure 2-4 What will drivers do in autonomous system [33]

The proposal is the development of content that features an AV managed content that will optimally integrate what the car senses on the external drive path and mesh it to a user desired task to maintain safety and engagement. This is the concept of entertainment in cars.

2.3 Entertainment in Transport Systems

Efforts to increase productivity during commute have been explored by different modes of transport systems. In airlines, games, videos, radio, and other relaxation methods are employed during flight. In cars and trains, passengers prefer engaging with activities like reading, browsing the internet, communicating with loved ones, among others. In the advent of AVs, different activities are explored as a substitute for recovered time.

Figure 2-4 shows the results of a study as to what activities the users of AV will want to engage in during transit [33]. Predominantly, the tasks are geared towards increasing productivity during transit featuring activities like work, relaxation, and social interactions, among others. To account for the same, manufacturers of vehicles are designing concept cars and models that will best fit the new technologies to deliver the best experience. To this end, games, remodeling of car interiors, AR heads up display (HUD), among others have been proposed or deployed in the modern cars. As of the year 2020, manufacturers like Tesla®, Mercedes-Benz® and others are paving way for the future of gaming in vehicles. Tesla introduced first game in cars (Atari games) playable in the screen (Statt, 2019). In early 2019, Mercedes-Benz® introduced a video game (Mario Kart) in the center screen [36], [37]. The deployed games are principally targeting a parked vehicle thus enabling the use of car steering wheel and pedals. As a development to the parked-car games, Audi®, holoride® and Disney team released an in-car VR experience focusing on passengers in transit [38].

Several concept cars have been tested by automakers with different features. Two of such concepts that are of special interest to this research is Zoox®, an Amazon owned robot-taxi and Chevrolet Env 2.0® [39], [40]. The concept cars featured an overhaul to the conventional interior design with a notable elimination of the current infotainment system. This imply that an alternative information/entertainment system is needed that best suits AV as well as support the new driving experience. The present research focuses on the use of VR systems for productivity and as such, only VR related strategies are considered.

Research towards productivity in cars using VR systems takes different forms and focus points. McGill et. al. explored the first on-road immersive VR with varying visual presentation of the real-world motion [24]. The authors investigated optimal visual presentations of motion in VR in a bid to minimize sensory conflict. To this effect, the authors utilized 3D video and 3D virtual scenes using Samsung GearVR headset during transit. From the design of experiment, variation of visual motion cues and scenarios were created using 360-degree video content. As expected, car and user rotations get mixed up in the VR HMD and as such, the authors described the steps for elimination or compensation of unwanted rotations. From the results, the paper found no particular best system that balances of immersion and sickness. As a primer to the study, experimentation of in-car VR use was recommended.

A paper [41] explored in-car VR to create a calm and mindful experiences for AV users. The authors utilized dynamic and static scenes to investigate the most ideal experience for a moving and a parked car system. In the study, congruency was explored in either, a static physical environment (parked car) with a static virtual environment (congruent condition) compared with static physical environment and a dynamic virtual environment (incongruent condition). The users experienced a fully immersed, under-water exploration movement synchronized (loosely) with the car motion. That is, the user movements were controlled by an outsider to correspond to car forward motion. On the static scene, the users were virtually translocated in a calming beach scene with no car motion in both car-movement and car-parked case. The authors reported that diving in the ocean in a moving car had lower levels of autonomic arousal compared to static VR in a stationary car condition. In addition, the authors noted that incongruence between car movement and VR content, which we refer to as synchronicity between cyber and physical world, affected nausea.

Another research utilizing in-car VR is reported in [42] targeting VR entertainment. In the setup, the particpants engaged in a rail-shooter game in a static (parked car) and dysnamic (moving car) environment. The setup features a synchronization of physical space to the cyber space in the sense that kinesthetic congruence between visual (virtual world) and vestibular information (from physical car movements) is maintained. This was achieved by relegating car motion (from onboard diagnostic board) as VR scene motion commands. The authors concluded that perceived kinesthetic forces caused by in-car VR potentially increases enjoyment and immersion while reducing simulator sickness as compared to a static environment. Other research touching on in-car VR have focused on challenges of passenger experience, cooperative game-play, VR/AR for driving, posture alignments amongst others [43]–[47].

The proposal to introduce VR in cars has mixed views and perception in research communities. On one hand, drawing from the discomfort formed in usage of VR system, some see it as a less feasible solution to the problem at hand [46], [48]–[50]. Others view it as a tool that can be channeled to tackle the problem or at least be a trade off with proponents arguing for its usability in elevating discomfort [38], [42].

From a review of literature, the position of this inquiry posits that, with proper utilization of stimuli and tasks, VR can be a potential solution to discomfort as well as a powerful tool towards productivity. From the review, when car motion cues and visual information from HMD are mismatched, there is a surge in nausea and general user discomfort [51], [46]. As such, synchronicity should be properly considered for in-car VR experience. Synchronized tasks are tasks that consider physical car attributes like acceleration, braking, turns and location and integrate that in the VR environment. This would take form as a scene in VR that accelerates or turns with every turn of the vehicle. Non-synchronized on the other hand features all other tasks performed in the VR that are disconnected from the actual car location and maneuvers. There might be utility in non-synchronized content but at its infancy, use of In-car VR with synchronized content is ideal. One such usage is applying VR as an infotainment system that gives contextual information to users.

This work focuses on gaming as a lucrative engagement that will be both entertaining as well as be an indirect environment contextualization scheme. We propose to evaluate the behavior of the driver in a driving context as described in literature with video and gaming tasks.

CHAPTER III: MATERIALS AND METHODS

3. MATERIALS AND METHODS

The section deals with the materials and methods used in the study. The overview of the study is as described by the flow diagram shown in Figure 3-1 below. Each of the elements is described below.

3.1 3D VR Contents

3.1.1 Experiment 1: Car collision scene

In this experiment, the relationship between hazards and simulated driving scene is explored. The target is to identify relationship that exists between hazards and physiological responses. To this end, left and right sternocleidomastoid from the neck were used to evaluate hazard response. As indicated in Figure 3-1, the experiment was carried out in an office setup with a seated driver. The scene was designed using Unity 3D. Figure 3-2(a) shows the experimental setup utilized. In the setup, 3D VR, Thrustmaster racing pedal and wheel and bio signal recording devices were utilized. A detailed explanation and setup of the experiment is found in chapter 4.

3.1.2 Experiment 2: Office setup of road monitoring and game task

The experiment a similar scene setup with a different interactivity. The objective of the study was to investigate the impacts of road monitoring using simple gaming mechanism. As such, the driver was not actively controlling the car but rather was involved in game interactions. The setup is as shown in Figure 3-2(b). A detailed explanation and setup of the experiment is found in chapter 5.

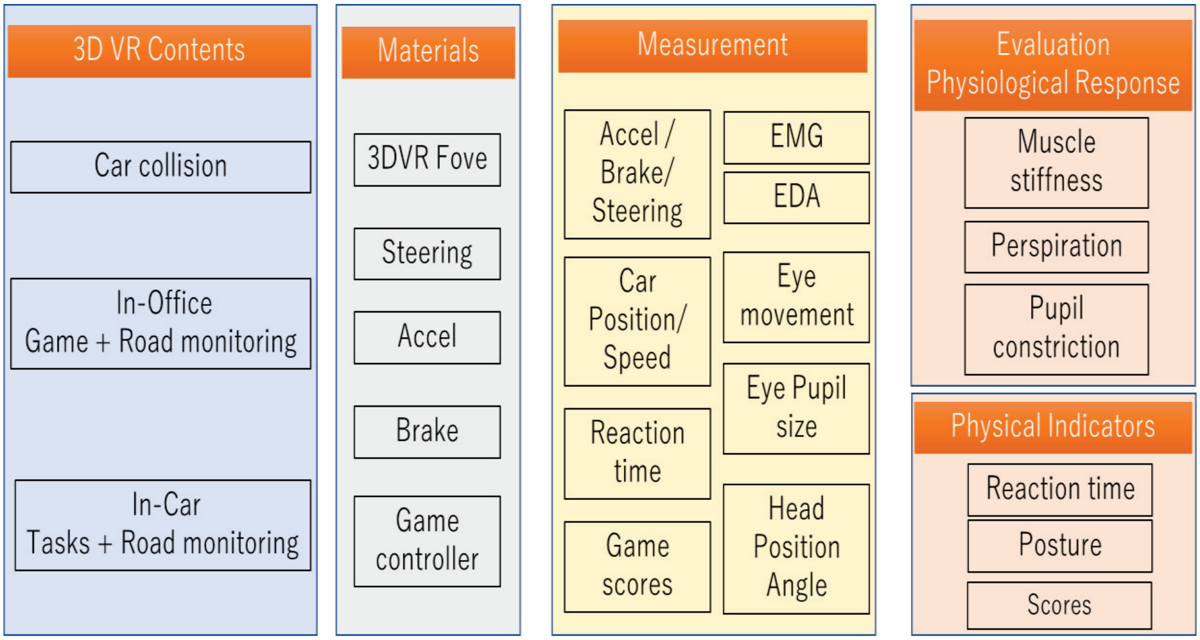


Figure 3-1 Proposed system

a) 3DVR and EMG recording setup

b) 3DVR setup in game control interface

Figure 3-2 Experiment one and two setup

3.1.3 Experiment 3: In-car setup of 3DAR

The experiment was conducted to investigate VR usage in an actual real-world setup. In the experiment, the users interacted with virtual environment that meshes with an actual physical world, driving environment thereby the qualification of augmented reality. The setup for the experiment is shown in Figure 3-3. In the setup, the test subject sat in the passenger seat with 3DVR allowing for virtual environment interactivity during flight. In the setup, the user experiences the physical somatosensory information generated by the car and experiences a corresponding effect in the virtual environment. A detailed explanation and setup of the experiment is found in chapter 6.

Figure 3-3 Experiment three setup

3.2 Materials

3.2.1 Unity 3D

The overall objective of the study was to investigate autonomous vehicle usage behaviors and trends. However, at present, AVs are not yet in operation. A substitute in literature has been on the use of VR and driving simulation to characterize the behavior.

The study employed Unity 3D game engine for the design of custom-made driving simulation. The choice was made because all commercial simulators are single units and do not allow for flexibility. Unity 3D game engine has been utilized widely in the research community as it allows designers to build realistic graphics as well as incorporation of physics interaction that are ideal in emulating real-life experiences.

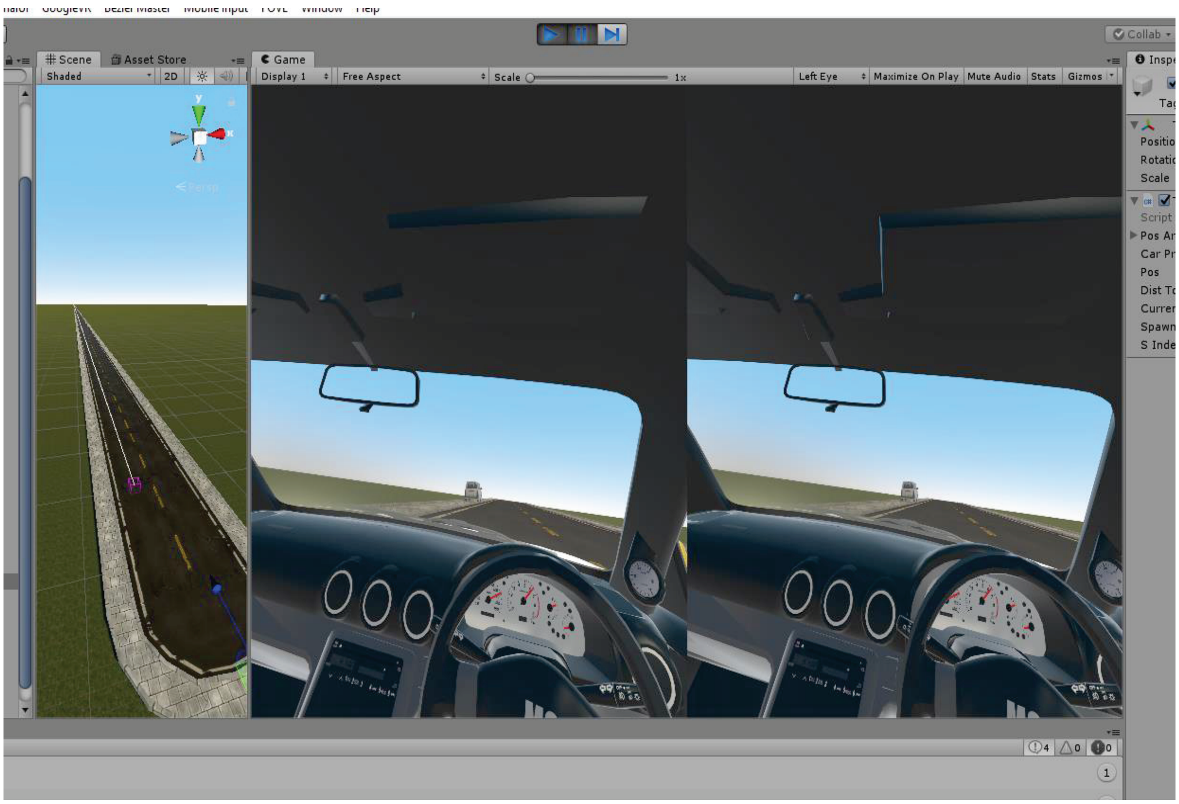


Figure 3-4 Sample simulator scene for experiment 1 in Unity 3D

The user performed all the experiments described above wearing a Head Mounted Display (HMD), in this case FOVE® VR. The VR gives out two cameras each targeting left, and right eye (Binocular VR) as shown in Figure 3-4.

Besides the driving simulator, the study targeted usage of additional tasks. To this end, game and video task were designed as an integral part of the simulation. For immersion of experience, a VR simulation was utilized as this has been found to be comparable with actual driving experience [52]. The simulation was run on a windows 10 PC with Intel® Core i7 processor and GeForce GTX 1650 graphics card. For steering, car maneuvering, and game controls, the study utilized joysticks and force feedback racing wheel (Thrust master T150) game pads as shown in Figure 3-5.

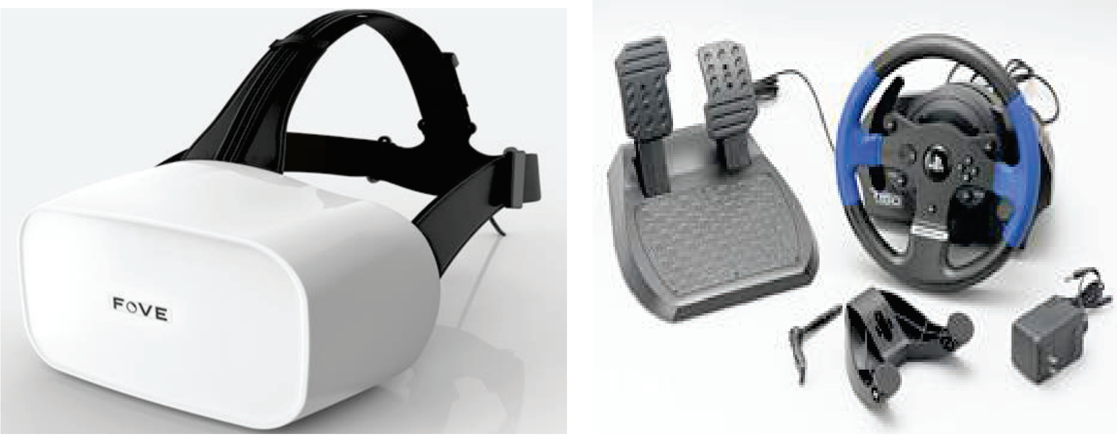


Figure 3-5 FOVE VR and steering wheel setup

3.2.2 Virtual Reality Headset

FOVE HMD was used as the VR of choice. This was because of its inbuilt eye tracking system as well as its position tracking mechanism. There are two main tracking mechanism in VR: inside-out tracking and outside-in. Inside-out tracking method uses camera or sensors placed on the tracked device and looks outward to determine its location relative to the environment. Headsets using this technology have multiple cameras facing different directions to get views of its entire surroundings. Example of devices using inside-out tracking is HTC Vive, with Lighthouse system, Oculus Quest, among others. On the other hand, Outside-in tracking method employs cameras placed in stationary locations outside the VR environment to track the position of markers/tracked device. Devices that utilized this technology includes original Oculus Rift with a constellation of IR LEDs and FOVE VR with IR sensor camera.

In the study, HTC Vive, Oculus Rift VR systems were unusable due to the tracking method in use. HTC Vive requires a fixed base station to track while Oculus Rift loses track when the environment changes as is the case in a moving vehicle. FOVE VR was thereby maintained in all the experiments.

3.3 Physiological Signals Measurement

Physiological signals have been applied as objective measures in varying fields and topics like emotion recognition, affective computing, decision making processes, among others [53]–[56]. Four of the commonly used physiological signals were considered; electrodermal activity (EDA), electromyography (EMG), Electrocardiography (ECG) and Electroencephalography (EEG). In addition, we include eye tracking data signal for gaze and pupil size. Table 3-1 below gives a breakdown of physiological signals describing the target response and processing complexity. From response time, stability, and ease of use, we identified ECG and EEG as unusable in the current application as shown (highlighted in yellow). For evaluation, three physiological signals were utilized: EMG, EDA, and eye pupil size. This section below describes the acquisition, processing, and analysis of the EDA, EMG, and eye tracker signals.

Table 3-1 A breakdown of considered physiological signals

	EDA	*EMG*	*ECG*	*EEG*	*Gaze*	*Pupil size*
Measurement Position	Palm	Neck	Heart	Brain	Eye	Eye
Measured quantity	Electric potential	Electric potential	Electric potential	Electric potential	Camera	Camera
Physiological response	Perspiration	Muscle Stiffness	RRI/HRV	Basic Rhythms	Eye movement	Pupil size
Response Speed	Realtime	Realtime	Approx. 30sec	Approx. 30sec	Realtime	Realtime
Evaluation Stability	Stable	Stable	Unstable	Stable	Stable	Stable
Ease of use	Easy	Easy	Easy	Difficult	Easy	Easy
Target Characteristic	Physiological arousal	Tension	Tension	Focus	Focus	Physiological arousal

Note: RRI = R-R interval, HRV = Hear rate variability

3.3.1 Electromyography (EMG)

We used Ag/AgCl electrodes positioned on the target muscle. The signal was pre-amplified using Polyam4B before passing to A/D converter (NI USB 6211). The flow of the signal is as shown in Figure 3-6 below. The raw EMG signal was sampled at 2 KHz with National Instruments NI USB-6211 connected to a laptop PC running MATLAB® data acquisition application. The signal was rectified and smoothed with moving average filter. The extracted feature is used for further analysis as reported in result section. The components of the DAQ unit are as shown above in Figure 3-7.

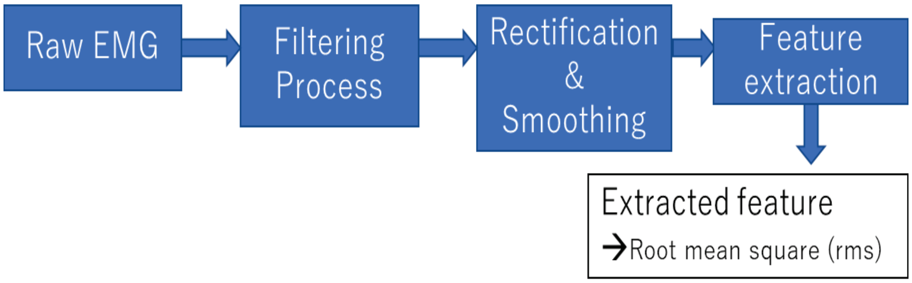


Figure 3-6 EMG signal acquisition and processing flow diagram

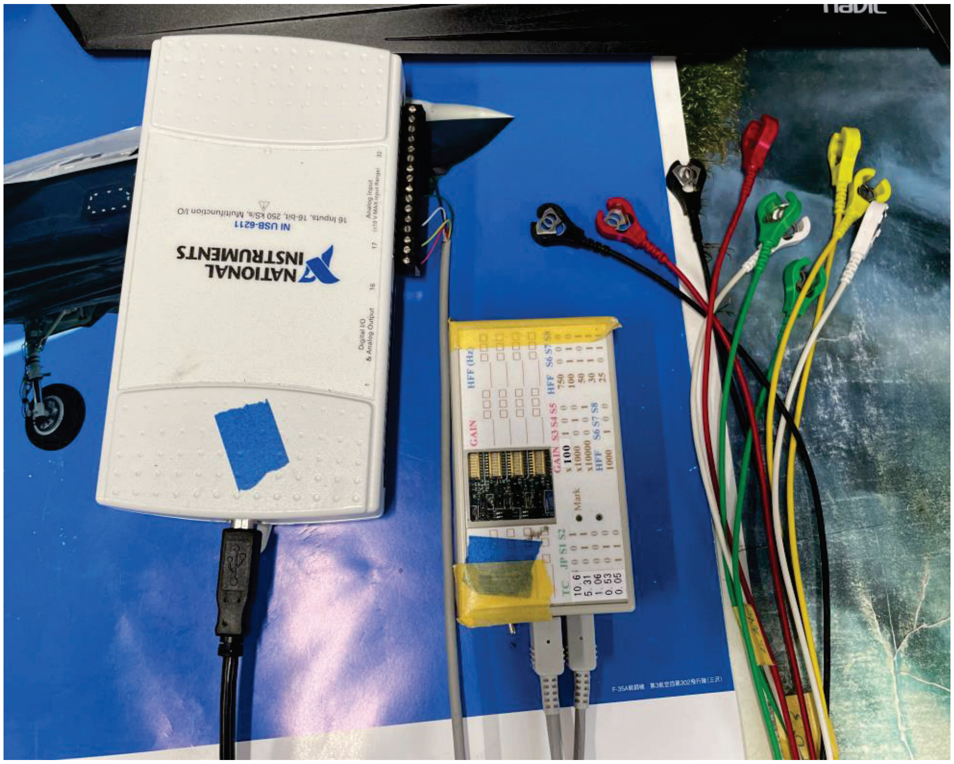


Figure 3-7 EMG data acquisition unit (DAQ)

3.3.2 Electrodermal activity (EDA)

EDA is derived from measured skin conductance (SC), converted from potential difference in the electrodes positioned in the skin of the subjects. A report by [57] gives recommendation for location of the signal as well as sampling rate. Based on the ease-of-use, palmar EDA (EDA electrodes positioned on the palm region of less dominant hand) has been shown to be sufficient to capture emotion (state) of the users [58]. As such, the study utilized palmar EDA with sampling rate of 1 Hz. The setup for EDA measurement is shown in Figure 3-8. The EDA sensor in use was MaP2220EDA.

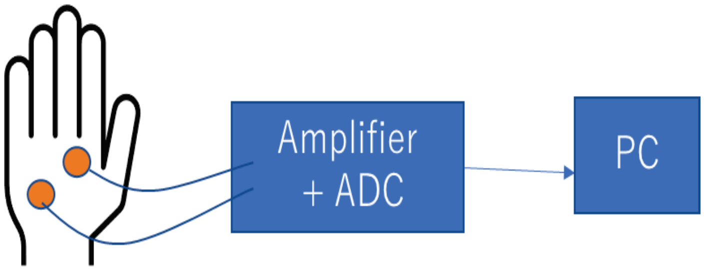


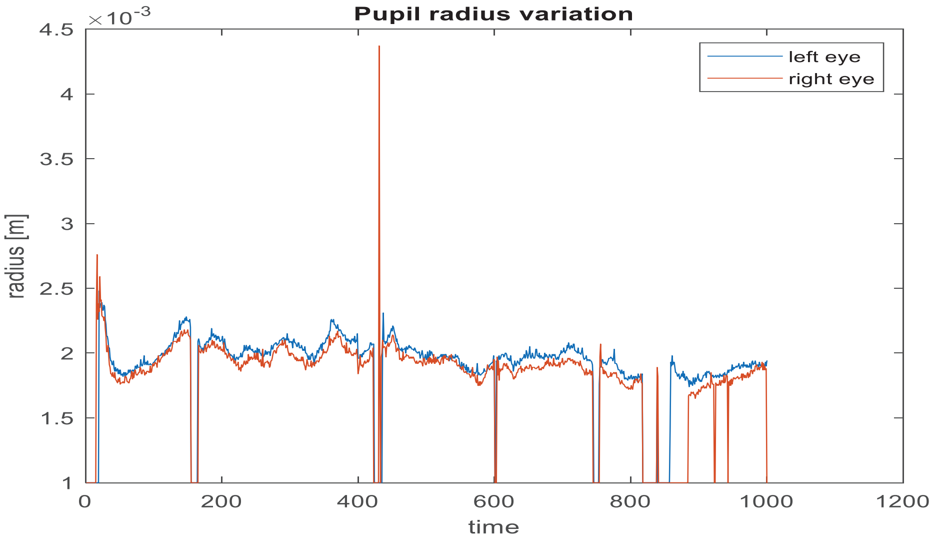
Figure 3-8 EDA measurement setup

3.3.3 Pupil size

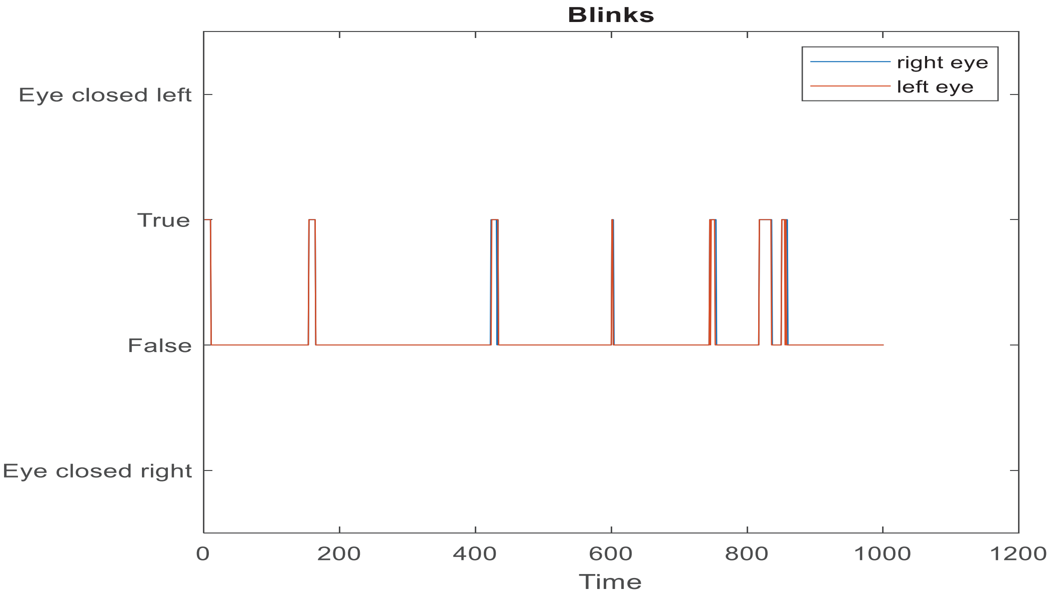
From literature, eye pupil size change based on the illumination (direct response) of the environment. The other reason for variation is focus point (accommodative response), with a constriction when the eye is focused on near objects. Other causes of change include drug use, emotions, health, among others. Amongst these, direct and accommodative response are important to this research. In the setup, we utilized a global illumination setting (source of light is skybox), to ensure uniformity in direct eye response. Concerning accommodative response, game and video elements used were positioned in the same location for consistency.

Research is replete with the parasympathetic and sympathetic innervation of the eye where it has been established that pupillary dilation is similarly caused by mental processing and engagement [59], [60]. The target of the research was to identify differences in pupil size which are explainable by engagement task. Pupil size was recorded from FOVE VR.

Figure 3-9 represent a sample pupil radius data collected during testing phase. From the figure, radius measurement fluctuates drastically during blink. As such, the recorded eye data was cleaned to remove blink and erroneous recordings which present when the eyes are opening or closing. Theoretically, left, and right eye pupil radius are equal. In the analysis of the data, we averaged the radiuses to get a more accurate representation for analysis.



(a) Pupil radius per eye



(b) Blinks per eye

Figure 3-9 Sample pupil radius data and corresponding blinks for left and right eyes

3.4 Measurements

The study utilized both physiological signals and physical hardware materials highlighted above to record data for analysis. From Unity 3D, the following data was logged for further analysis.

I. User Inputs: This included all user supplied control commands like steering, accelerator, braking, and joystick button presses. The data was logged in csv format.
II. VR data: The positional data of VR in 3D space that indicate head position and rotations.
III. Eye Tracker: The VR gave gaze vector and pupil radius from the inbuilt eye tracking software.
IV. Virtual vehicle data: From the virtual vehicle, position, velocity, rotation, and other related data was collected for analysis.

The recorded data was analyzed using Matlab® and is reported in the results sections of each experiment.

CHAPTER IV: HAZARD RESPONSE DURING ACTIVE DRIVING

4. HAZARD RESPONSE DURING ACTIVE DRIVING

4.1 Introduction

This present work sought to evaluate surprise responses of the drivers, that is, the reaction of the driver and the effects that surprise has on car-handling performance in a threatening situation. We focused on unpredictable scenarios (hazards) and evaluate driver performance in such conditions. Previous research dealing with hazards have not addressed the relationship between hazards and car handling. As such, one of the contributions of this work is to point out any existing relationship between performance and surprise in driving environment.

To explore the effects of surprise on performance, we will make note of the relationship that exists between hazard response and pedal errors. The authors in [61] defined pedal errors as cases where the driver mistakenly presses the wrong pedal or does not press any of the required pedal. In a real driving environment pedal misapplication is a rare occurrence nevertheless a significant one. There is no mechanism inbuilt in the current vehicles to accurately predict and override a misapplication [61]. In an emergency (sudden objects), pedal errors are expected to increase. A paper [62] focused on pedal application in driving and concluded that, error was dependent on foot position and type of driving sequence e.g. parking. The research considered pedal misapplication as any event where the driver did not take corrective action when the situation required so.

In the experiment, we presented potential (staged) crash objects appearing at 30 - 120 Meters from the driver's current position. This corresponded to 0.7 to 3 seconds with the preset driving speed. We wish to analyze reaction time as one of the car-handling indicators of the driver as different objects appear on driveway.

We propose to perform driver analysis using one of the readily available bio-signal, surface electromyography (sEMG), to infer threatening situation and vehicular driving data to analyze performance in surprise events. In an impeding collision, the body involuntarily prepares for impacts through a series of neurophysiological responses. Amongst these responses includes muscle toning to protect vital parts of the body. In particular, the neck experiences a considerable amount of muscle tension to keep the neck and spine intact before and after impeding impact. These instances of muscle toning are used to infer events that are undesirable (threatening) to the driver. We found little research geared to this inquiry points. A paper [63], sought to understand the response of a driver to darkness enhanced startle in a tunnel driving. Other than this, the authors did not find any other paper exploring neck sEMG for driver behavior analysis.

In summary, the objectives of the research are as follows:

a. Utilize physiological response, from SEMG of the neck, to recognize / capture hazard responses. The main target is to underscore the relationship between performance and surprise in driving environment.
b. Analyze reaction time of hazardous (staged) crash objects as one of the car-handling indicators of the driver.

4.2 Methodology

Driving simulation was designed using Unity3D engine. 3D Virtual Reality (3D-VR) Head Mounted Display (HMD) from FOVE® was used instead of fixed projections or monitors. The simulation was run on a window 10 PC with IntelI Core i7 processor and GeForce GTX 1070 graphics card shown as graphics rendering unit in Figure 4-1.

The experiment was setup to capture drivers neck EMG as shown in Figure 4-1. Two electrodes are connected to left and right Sternocleidomastoid (SCM) muscle in a bipolar connection.

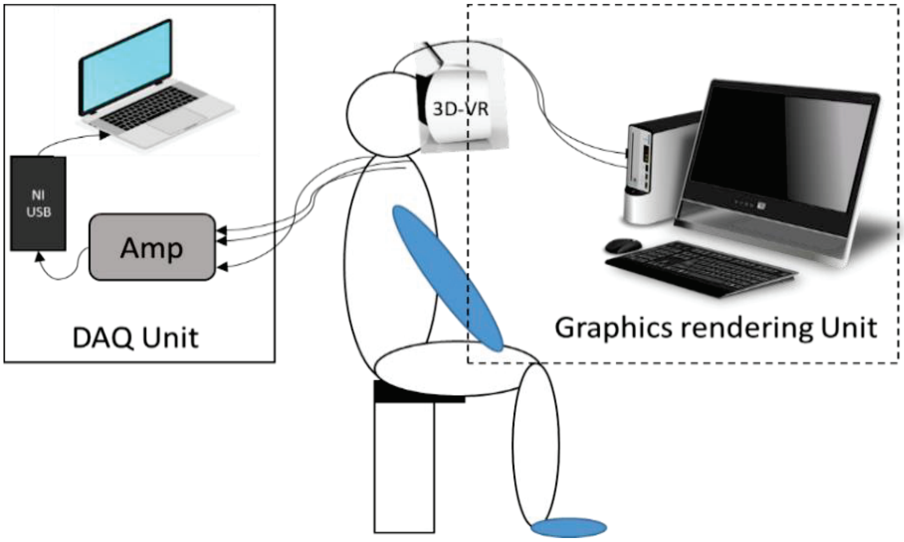


Figure 4-1 SEMG recording and simulation setup

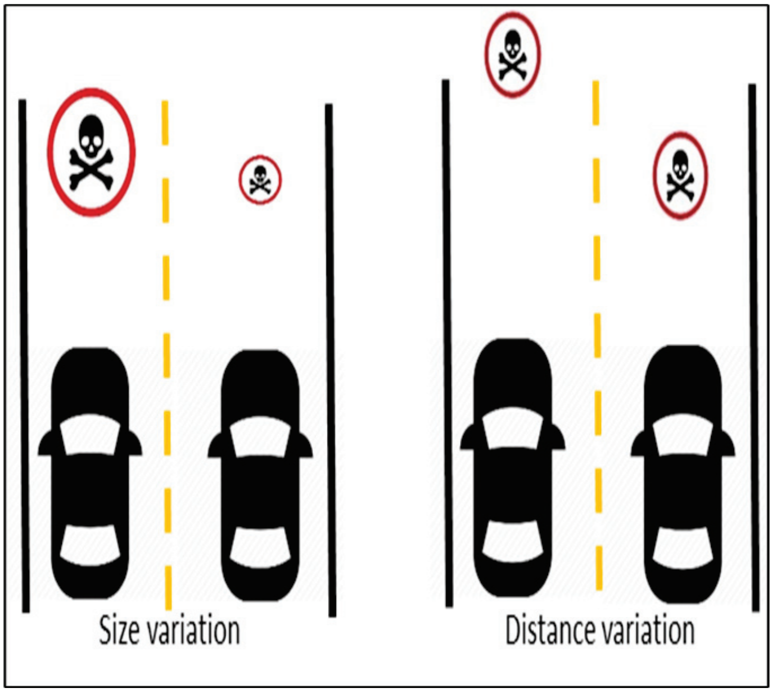


Figure 4-2 Conceptual illustration of size and distance variation in the scene

4.2.1 Driving Scene Setup

The scene is setup with the subject seated in the driver's seat of a virtual car with a road and clear blue sky to avoid distractions of subject's attention on scene details. Figure 4-2 shows the scene design with popup objects varying with size in the first instance and popup distance in the second. Figure 4-3 shows sample popup objects utilized in the scene. The driver encounters 15 randomly appearing stimulus (triggered objects) to elicit response. The maximum attainable speed was set at 40 m/s. The driving mode lasts for about 20 minutes driving in a straight line.

Active driving mode used Thrustmaster® steering wheel and pedals (acceleration and braking) as reported in a paper [52]. The road characteristics are as follows; the total width is 10 M, and a walking path on both sides of width 1.5 M. The speed was to be maintained at a target speed (greater than 35 m/s). This implied that the driver would keep his/her leg in the acceleration pedal. The driver was instructed to keep left unless when necessary (avoiding collision). The deviation from middle of lane one is recorded as an index to show steering wheel activity before and after an obstacle stimulus is presented. From this index, deviation is classified as normal if the car is within the driving lanes, severe if the car reaches the pavements and dangerous is the car hits the walls. Since the car was in the middle of the left lane, negative deviations indicate left turns and positive deviations (dominant) indicate position of the car in the right lane.

Prior to the experiment, the driver was given a test scene for them to familiarize with the car control and object avoidance as they appear. This lasted between 5 – 10 minutes or until the driver was confident of the controls.

4.2.2 Data Analysis

Since the objective of the study is hazard response, only data around a trigger event was considered to avoid motion artifacts. The authors in [64] places driver's physiological response between 1 – 3 seconds. Based on this timing information and the fact that the stimulus was set to pop-up between 0.7 – 3 seconds as described above, we considered 3 seconds prior to an event as baseline and 3 seconds later as the response window.

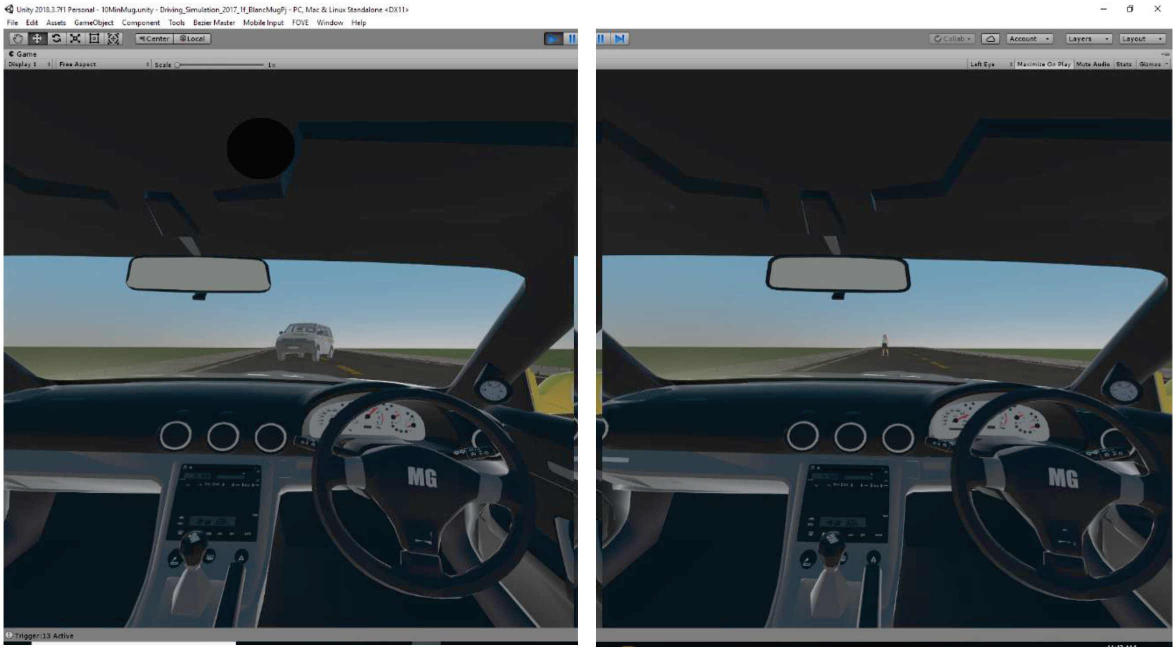


Figure 4-3 Unity3D sample scenes with car and humanoid popup objects

The response window chosen captured active or passive driving reactionary behavior local to an event. The response prior to stimuli was chosen as 3 seconds to capture an equivalent amount of physiological data for comparison purposes. The recorded data was analyzed using custom-made MATLAB® functions to high light relevant features and relations as shown in the next section.

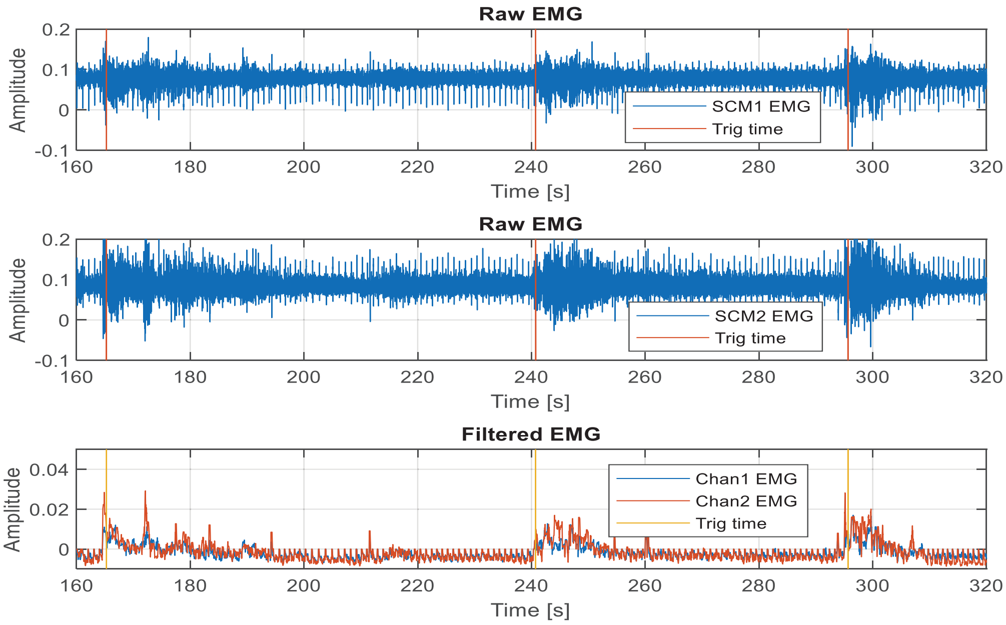
4.2.3 Artifacts in Neck EMG

SEMG of upper body parts are highly affected by heart pulses. Presence of electrocardiogram (ECG) artifacts increases the root mean square value of the EMG while lowering the median frequency of the signal. This is particularly an important problem in neck sEMG because of its low amplitude nature. Artifacts in the EMG signal is due to the presence of the carotid artery near the SCM muscle (target muscle) which has one of the strongest ECG pulses in the human anatomy. From literature, the commonly employed method for elimination of ECG artifacts is the use of High pass filter with 30 Hz cutoff frequency [65]. The demerit with the method is the attenuation of signals below 30 Hz. In this work, to avoid changing the spectral characteristics of the signal, we employed median filtering to the rectified and filtered signal to eliminate ECG peaks.

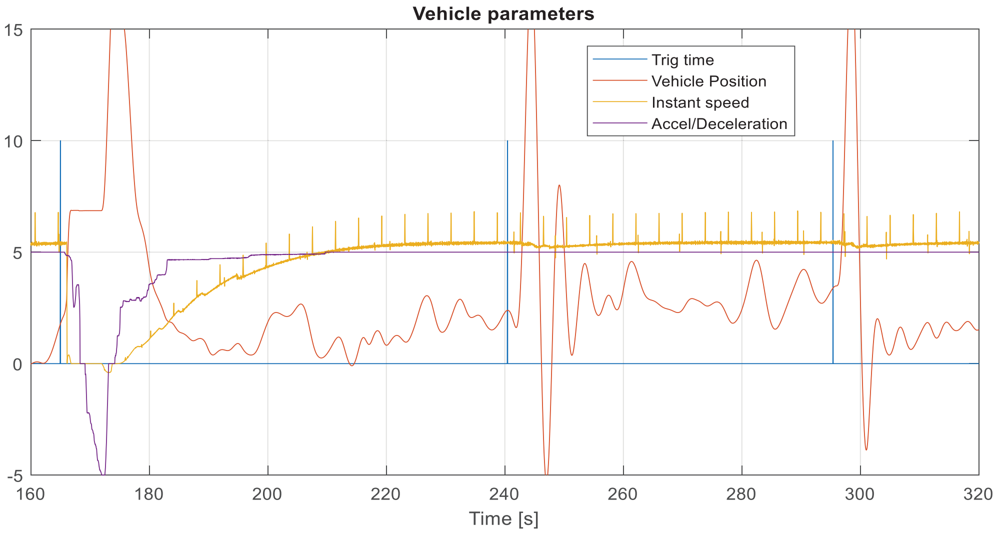
4.3 Results

The following section shows a representative sample of sEMG signal and car-handling parameters. Each of the considered car-handling parameter, i.e., reaction time, wheel/paddle activity and deviation are further expounded below. EMG response and its relationship with various objects is described in ensuing sections as well. Figure 4-4(a) shows raw contaminated EMG and corresponding filtered EMG. From the figure, there is an increased EMG activity after a stimulus is presented. ECG peaks are evident when there is little or no activity on the neck. Figure 4-4(b) indicates that the driver is actively steering to keep within lane one and accelerating to maintain target speed.

From Figure 4-4(a), we noted that even during active maneuvers like braking and steering, neck sEMG did not report significant change as compared to a hazard (trigger) event. sEMG response was further processed using Area under Curve (AUC) and is further explained in a later section. From Figure 4-4(b), vehicle position curve changes drastically in the first trigger, a case where the car collided with an object as further confirmed by reduction of speed and acceleration pedal input. The next two triggers are a case of no collision after active steering. The car position deviates greatly (from centerline) at first and then the changes become gradual.



a) Raw and filtered EMG signal



b) Car performance indicators

Figure 4-4 EMG response and corresponding vehicular recorded parameters

4.3.1 Reaction Time

Figure 4-5 shows sample data of relevant parameters extracted from car handling and EMG data for experienced unlicensed drivers while Figure 4-6 is for licensed drivers. The experiment evaluated the reaction time as the time before acceleration pedal release or an initiation of active steering activity as shown in Figure 4-5 & Figure 4-6. As shown in Figure 4-5, novice driver's performance shows greater collision compared to experienced driver with no significant difference in reaction time. Significant difference is shown in the braking activity of the two, with experienced drivers braking far less instances. This is attributed to the real-life driving experience gained in car environment.

4.3.2 Deviation Index

The plot in Figure 4-5(a) shows the rate of change of position on the x-axis (lateral velocity) and the corresponding AUC in bar graph. From this, lower deviation was noted whereby the driver did not engage any harsh steering maneuvers. Either the trigger object is far enough to allow for smooth transition or there was no corrective action taken (no sufficient time to make moves). As shown by H30 object, the driver did not initiate any corrective action, which led to collision; this is a case of very short reaction window for any action. On the other hand, H120 shows a case where the driver overreacts and take severe turns leading to over steer. In Figure 4-5(b), H120 event shows a slow reaction time and a high deviation with no acceleration pedal release.

4.3.3 Pedal/Wheel Activity

Pedal and steering wheel activity was used as car handling indicators. A case where no release of pedal was not required is when the obstacle was far. As shown in Figure 4-5(b), the driver released the pedal in at least all the objects presented. The results suggest that cases of unreleased pedal constitute a pedal error. The objects H100, H120, H80, Truck1, and Van80 have no pedal release. We concluded that a H80 and Truck1 are case of pedal misapplication owing to insufficient processing time. The two events are singled out because they resulted in collision implying that an action was needed but none was taken.

From the results in Figure 4-5(b), steering wheel activity and pedal release happened at the same time. These results may have been influenced by the fact that the driver was ready to take evasive turns at the sight of an object. The order of occurrence of steering time and acceleration pedal release changed from time to time, but braking time was the slowest in the order of occurrence. From the results, the driver chose steering in at least all cases as shown in the braking response in Figure 4-5(d).

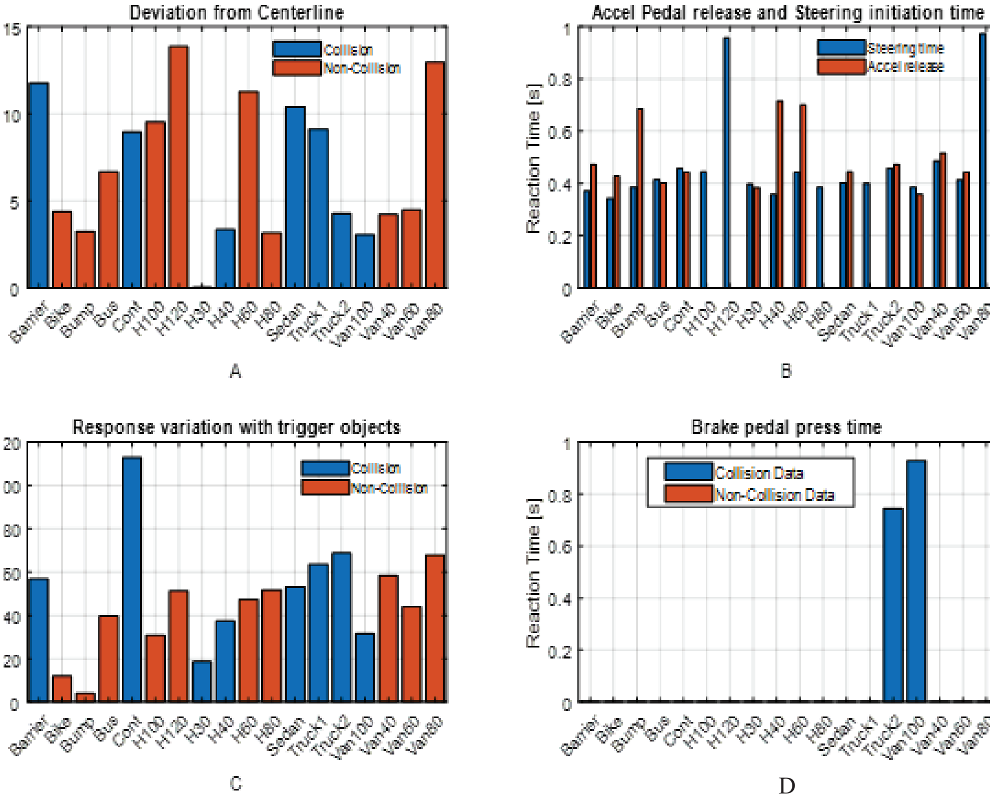


Figure 4-5 Experienced drivers performance index

Performance index: A) Deviation from mid-line, B) Reaction time of steering and acceleration pedal, C) EMG response and D) Braking reaction.

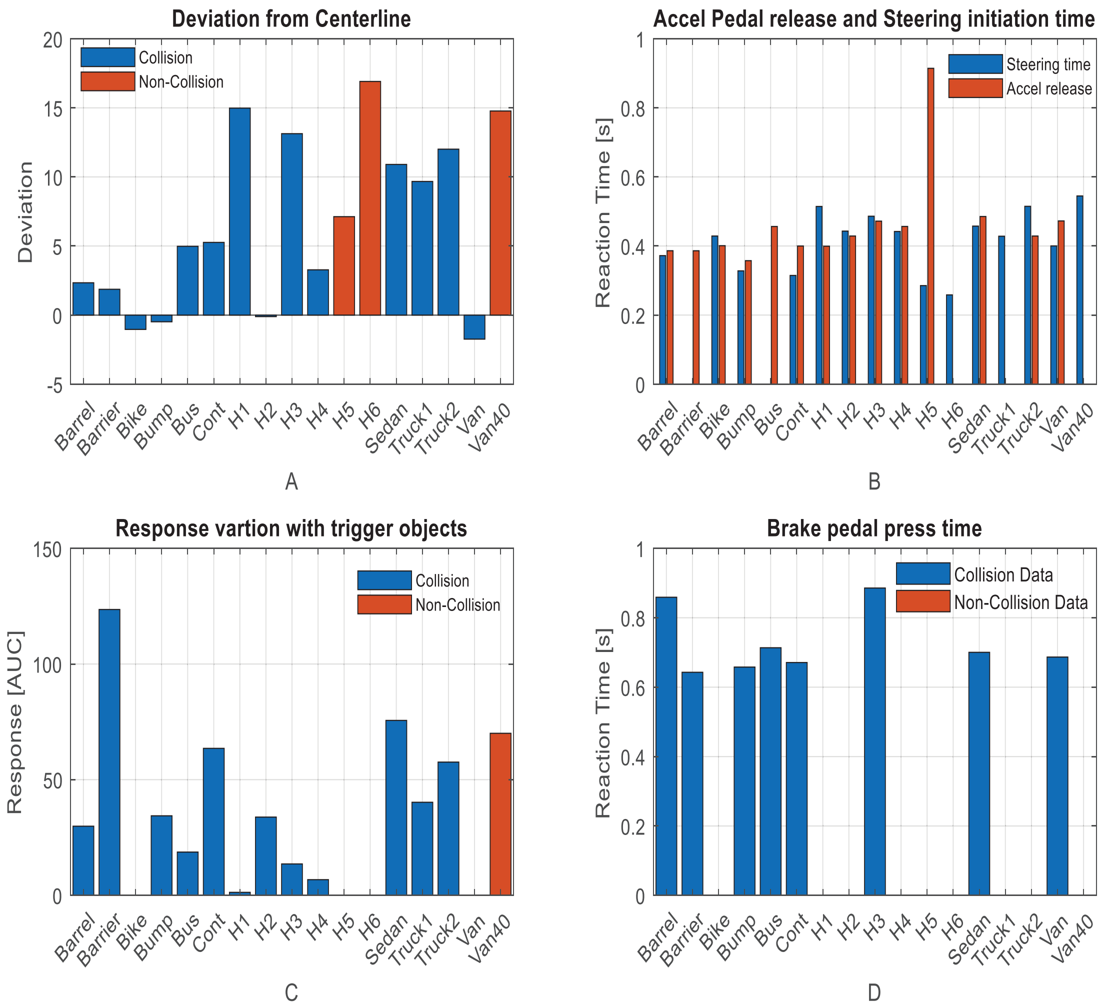


Figure 4-6 Performance index for non-licensed drivers

Performance index: A) Deviation from mid-line, B) Reaction time of steering and acceleration pedal, C) EMG response and D) Braking reaction.

4.3.4 Variation of EMG Response

The AUC for the processed sEMG is shown below with respect to specific events. The response AUC herein referred to as response is compared with type of object, and distance of presentation as well as collision or non-collision event. We sought to understand the relationship that exists between response index with distance and size of the object. The threat level was significantly high for big objects and short distance. Figure 4-7 shows deviation and response variations. Figure 4-7(a) shows a slight relation of response with the appearance distance. Figure 4-7(b) shows a clearer relationship as expected.

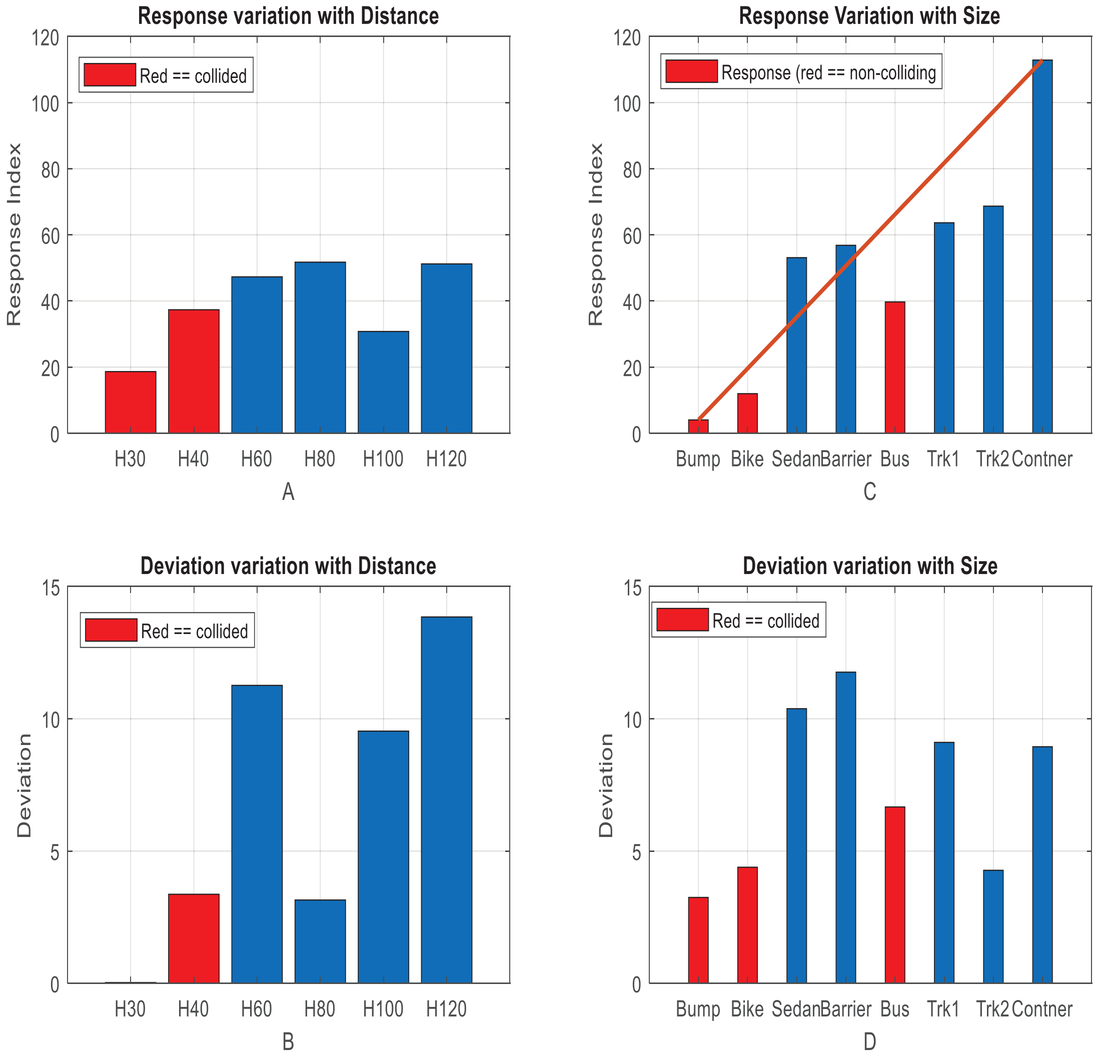


Figure 4-7 EMG response with size and appearance distance

4.4 Discussion

This study was conducted to highlight the current needs of assistive driving technology and risk assessment in hazardous events. Hazard response index in a real-time driving would be highly informative as has been made clear by several researchers. In a driving environment, any instance or event that the driver considers as hazardous shows up in various physiological processes. Therefore, we strongly feel that physiological analysis is the best-suited frontier to address the problem of driver behavior.

From the results, sEMG response increases with increase in perceived threat level. Deviation on the other hand did not show linear relationship with object size or distance. In all the stimuli presented, the driver recognized and prepared either for collision impact or avoidance maneuvers. This parameter is as shown in reaction time of less than 1 second.

Car-handling results suggest that braking information by itself would not fully characterize driver behavior. This is from the fact that drivers showed inconsistent tendencies of use/non-use of brakes. As such, braking information should be considered with other complementary data. In this experiment, we have focused on an experienced driver (more than 20 active years' experience) to point out the availability of hazard response. A paper [64] presented the "volleyball-paradigm" with the conclusion that all drivers irrespective of driving experience will be surprised by sudden objects in the driveway. Our findings showed that in a surprised state, driving errors increases.

4.5 Limitations

The challenge we encountered when dealing with response is habituation; a situation where a repeated stimulus elicits less and less reaction. For the study of hazard response, the choice of stimuli and the frequency of appearance should be taken into consideration. Novel information is desirable and as such, a good design of experiment and variation of stimuli is important. Another challenge was the use of 3VR-HMD. Although with its advantages in realistic scene presentations, users had visual discomfort in prolonged usage time. This has been reported as eye fatigue and in extreme cases, motion sickness.

CHAPTER V: ROAD MONITORING USING GAMING

5. ROAD MONITORING USING GAMING

5.1 Introduction

The overall objective of the work is to study driver behavior in an AV with gamified tasks in a 3D VR simulated driving environment. As previous studies have shown, boredom in an AV particularly in monotonous route would be far worse than in a conventional driving experience [31]. As such, with the introduction of an AR, users would be presented with new content overlaid in any route, making the journey enjoyable and less tedious. We propose a game designed to be played by the driver of an AV during autonomous mode. The game interactions are simple to avoid over-immersion at the expense of the environmental awareness as recommended by [43]. Additionally, gaming elements appear within the driving region of interest. This will assist indirectly in road monitoring and increased Situational awareness.

Awareness in driving has been identified as key to safe driving by several researchers [26], [66], [67]. At the onset of level 3 automation in AV, concerted efforts will be needed to maintain drivers visual search path to the driving environment. The reported cases of traffic incidences involving self-driving cars have partly been due to failure of the safety driver being disconnected from the environment [7], [28]. It is hoped that as AV develops, there will be perfect system performance but until then passengers and drivers alike will need to be aware of the developing situation on the road. One such way is use of un-obstructing AR games to guide vision to emerging/developing situation.

From [6], a fallback-ready user should be receptive to requests or eminent vehicle system failure whether a takeover request is issued or not. This calls for sustained vigilance on the driver side which is the focus of the current work. As such, the current research is concerned with the following:

a) Investigate how well the driver can recognize threatening driving scenarios while engaging in a game. This will be indicated by the time taken in accurately pressing appropriate button.
b) Evaluate driver's engagement with the gaming elements. Based on the interaction model, the driver may be engrossed in the game and fail notice a flaw in AV judgement or issued TOR. Alternately, the game may be non-engaging to the user leading to signs of disinterest. Either of the two scenarios will be useful feedback to the AV as this will inform the state of the driver.
c) Analyze game score profile to make inference on the drivers' state. Game scores will be used as an indirect measure to infer engagement and by association, vigilance. The profile formulated by intercepted gaming objects will be used in design recommendations of an AR game. In-game eye gaze tracking is used to confirm road monitoring.

The contribution of the present study is investigation on the use of VR and head mounted display as an alternative in-car infotainment system and characterization of driver state using gaming modalities. A business case for level 4 and above is well captured by [68] where engagement state and visual attention metadata captured is applied in tourism. The current paper, as a pilot study seeks to shed light on design considerations for infotainment systems. The findings will be applied in a real-world environment with a moving car to study various aspects of entertainment in an automated vehicle.

5.2 Methodology

5.2.1 Driving simulator

We designed a custom car simulator scene with Unity 3D game engine for driver analysis. In the configuration, a virtual car is configured on rule-based autopilot (use of waypoints) to mimic autonomous drive. Thus, no control inputs were required from the user. The vehicle was designed to move in a straight path (along z-axis) with minimal speed variation and turns.

A rural terrain was adopted with asphalt two lane road and minimal terrain details. The scene was designed to be monotonous with only road markings, greenery (grass) terrain all through on a clear blue sky. This was done to dissuade user's gaze from wandering to terrain details but rather focus on the gaming relevant objects (pop-up traffic and game elements). Fove® 3D Head Mounted Display (HMD) was used for VR content rendering in the prototype game. The simulation was run on a windows 10 PC with Intel® Core i7 processor and GeForce GTX 1070 graphics card.

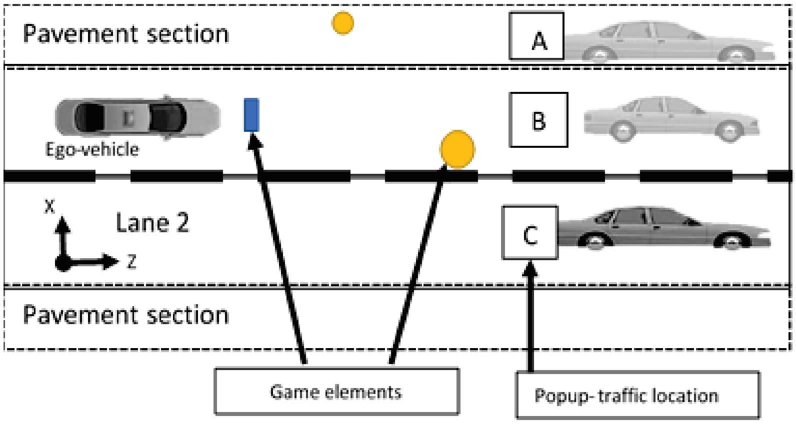
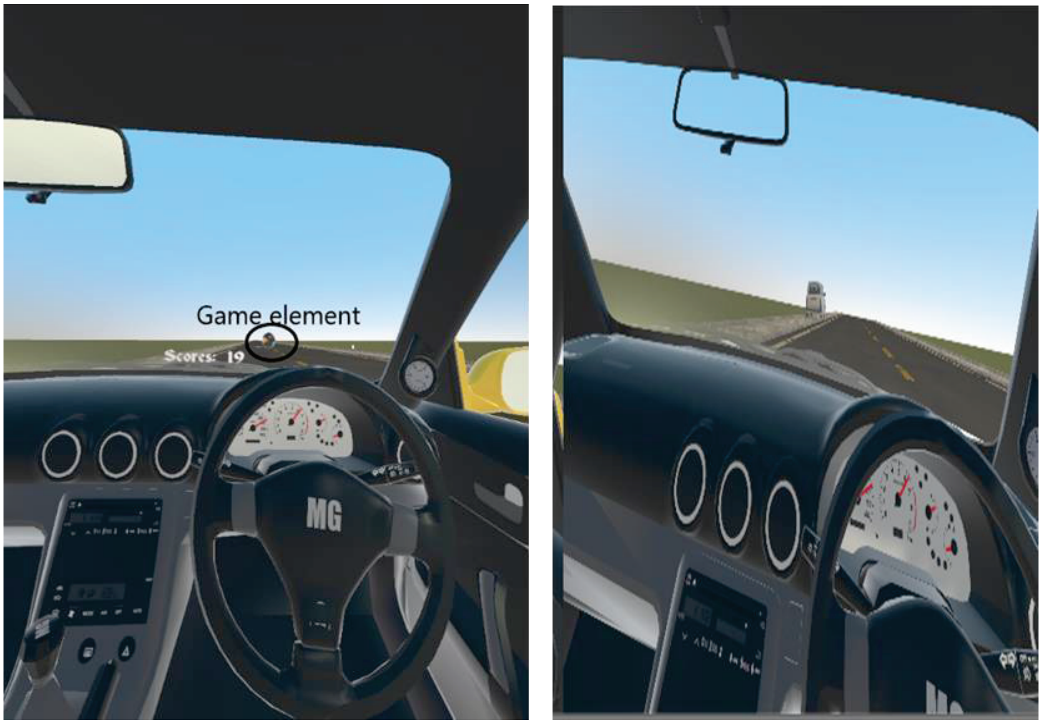


Figure 5-1 Simulation scene setup showing ego vehicle, game elements, and popup traffic.

In the design, we included staged popup traffic events to assess the driver's threat recognition time. The setup is as shown in Figure 5-1. The ego vehicle moves along the z-axis in lane one of a two-lane drive path. Game elements comprise a controllable (paddle) object (denoted in blue) and corresponding collectible objects (shown in yellow) that appear along the drive path. Popup traffic appears in locations A, B, or C. Popup traffic appeared after every 2 Km in a total of 25 Km distance covered cruising at a constant speed of 30m/s. Twelve (12) popup instances were displayed for each experiment. The test subjects were required to press a button immediately after popup traffic appeared. The entire drive-path region of interest covers the pavements and the two lanes, as shown in Figure 5-1. Figure 5-2 shows sample scenes with popup traffic and game elements as experienced by the driver.

5.2.2 Game mechanism design

The paper proposes to introduce gaming in car as a pass-time activity that will improve engagement as well as offer entertainment. On the game setup, the driver is actively engaging with elements on the road in while monitoring traffic. A controllable paddle object (player) is located a few meters from the cars' position which is clearly visible by the driver. The paddle slides along x-axis and is translated by the position of the car (z-axis). As the car moves autonomously, collectible objects are spawned ahead on the drive path by the gaming engine as shown in Figure 5-2(a).



(**a**) AR-Game elements view (**b**) Popup traffic vehicle

Figure 5-2 Conceptual illustration and sample VR scene of drivers view.

When the controller paddle (Unity 3D game object) collides with the mesh of the spawned object, a score is registered (intercepted) and the contrary for missed object. This is made possible by Unity 3D physics engine that checks for interaction of game objects. Missed objects will be recorded alongside the spawn point to analyze scoring profile of the position.

The driver moves the paddle position to intercept AR-Game spawned objects (elements) using a physical paddle controller shown in Figure 5-3. Player increases points upon a successfully intercepted object. In case of a missed object, a penalty is executed (decrement in displayed score) and data is recorded for further analysis of the missed object profile. Score progress is logged and displayed in the dashboard of the car. Gaze information was recorded using inbuilt eye-tracking system of FOVE® HMD. The data is logged together with car position and game score progression for every frame at a sampling rate of 65-75 frames per second.

We propose to set up Video on HUD in such a way that the driver can transition from video to road monitoring effortlessly. This is achieved by projecting the contents in a HUD type of screen as opposed to having the video player located below the drivers view in a cockpit as is the case in current car design. With this setup, the video is rendered in the upper part of the windscreen, leaving enough window for road monitoring. The setup is meant to reduce time taken to have eyes on the road.

5.2.3 Experiment setup

The subjects sat comfortably in an office chair with the camera view inside the car positioned in a typical driver-seat in a 3D-VR environment shown Figure 5-2(b). Figure 5-3 shows a test subject using 3D VR and steering wheel input controls for the game. We used Thrustmaster® steering wheel attached to the PC running the simulator for popup object buttons and game controller. The subjects were given a test scene of about 5 minutes to familiarize themselves with the control protocols. When fully mastered, a logged experiment was conducted ranging between 20-25 minutes.

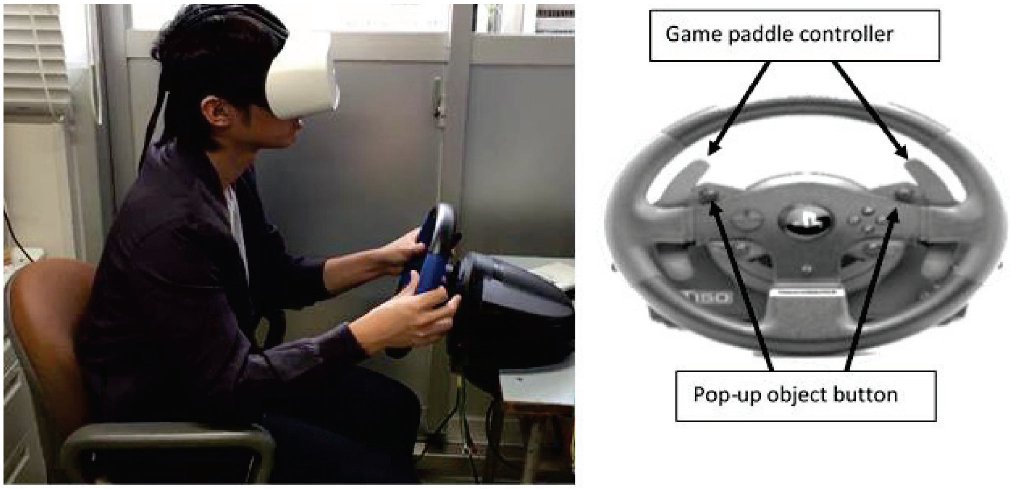


Figure 5-3 Test subject with 3D VR Head mount display and driving steering wheel setup

The user was expected to recognize the threat and push a corresponding button on the steering wheel shown in Figure 5-3 as pop-up object button. No auditory warnings were issued when the traffic appeared. Therefore, the driver relied on visual search to identify relevant information from the drive path and react accordingly. We performed the experiment with the user engaged in a game and compared the threat scenario recognition time to a case where the user has no or mild physical engagement (i.e., watching a video clip or no-task). The time taken (recognition time) to make a judgement of the object is expected to be impacted by the task or the driver's loss of attention. Interaction with the AR elements is evaluated in the form of game scores and gaze information.

5.2.4 Participants

Students comprised the participants in the study and were recruited following approval from the relevant ethics committee. Thirteen subjects took part in the experiment with an average of 26.6 years (std 6.2) from different nationalities. Real-life driving or gaming experience was not considered in the current study. A preparatory drive scene was presented prior to recording of data. In this test, the subjects were introduced to the controls and buttons as well as the general objective of the experiment.

The participants were divided into two groups, control group (3 subjects) and the test groups (10 subjects). The control group were presented with the tasks in random order while the other group were presented with gaming task to avoid pre-exposure. Each subject's gaze information, button presses, scores and interaction with game elements is logged in an excel file for further processing. Each recorded session lasted between 20-30 minutes for all subjects. No incentives were offered to the subjects. Data analysis was performed using MATLAB® software.

5.3 Results

5.3.1 Recognition (reaction) time

5.3.1.1 Comparison of tasks

To compare the performance of recognition time with different tasks, the control group tried the three tasks in random order. The performance is evaluated as shown below. Figure 5-4 shows a boxplot of the recognition time recorded in all the popup cases with or without a DRT. The evaluated tasks: No-Task, Game (AR-Game), and Video, had a recognition time difference of less than 1 s. for the subjects. Outliers in a No-Task scene represent instances where the driver was not paying attention to road events. The figure shows a case where driving with AR-Game would have a slightly slow recognition time with an advantage of consistency (a compact inter-quartile range).

There were statistically significant differences between the means of the groups as reported by one-way ANOVA ($F(2,33) = 4.34$, $p = .0213$, $\eta2 = 0.2081$). From the figure, driver in No-Task had the best recognition time (mean = 2.492, std = 0.083) and AR-Video (mean = 2.506, std = 0.179). AR-Game, (mean = 2.627, std = 0.081) was the slowest as expected.

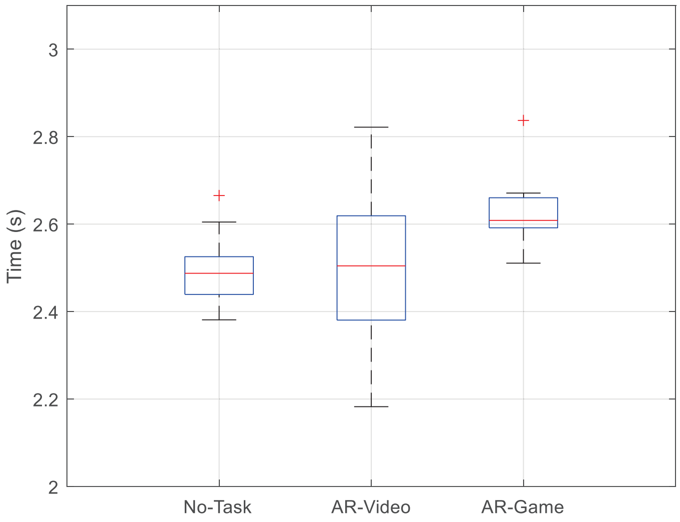


Figure 5-4 Recognition time of driver with different engagement.

In No-Task and Video tasks, the user's hands are not occupied with any activity and as such, pressing of buttons is instantaneous immediately traffic pops up. In the case of an AR-Game, the user is actively controlling a gamepad and takes more time transitioning to button press from active game control. A noticeable difference is an interquartile range (IQR), which was found to be 0.09, 0.2, and 0.07 s. for No-Task, AR-Video, and AR-Game tasks, respectively.

5.3.1.2 Gaming recognition time

The focus of the study was to investigate the impacts gaming would have on the reaction time. Figure 5-5 shows the boxplot of the recognition time for 10 of the users evaluated in the experiment. In all the cases, the drivers reacted within 3 seconds after pop-up traffic. The data captures a case where the driver did not press any button within the time period. This is shown as an outlier in driver no. 7. In the plot, the line represents the median and the boxes are the interquartile ranges (IQR) of the 12 pop-up instances.

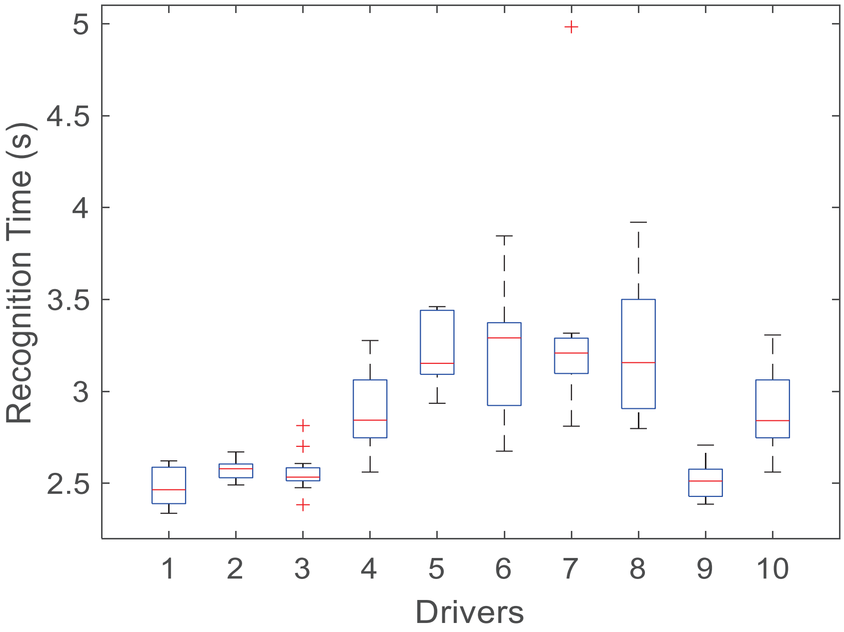


Figure 5-5 Overall AR-Game reaction time for drivers

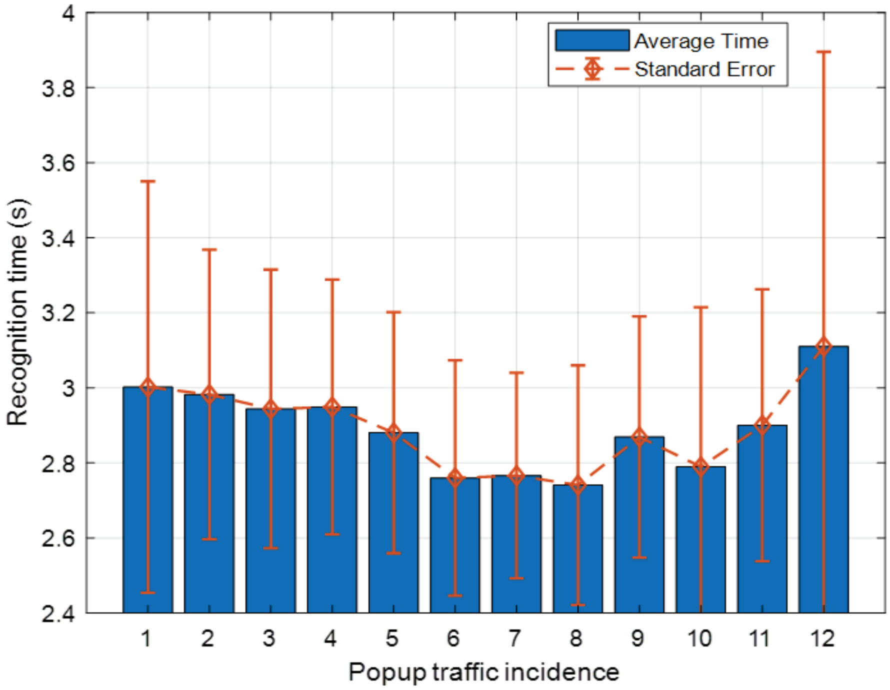
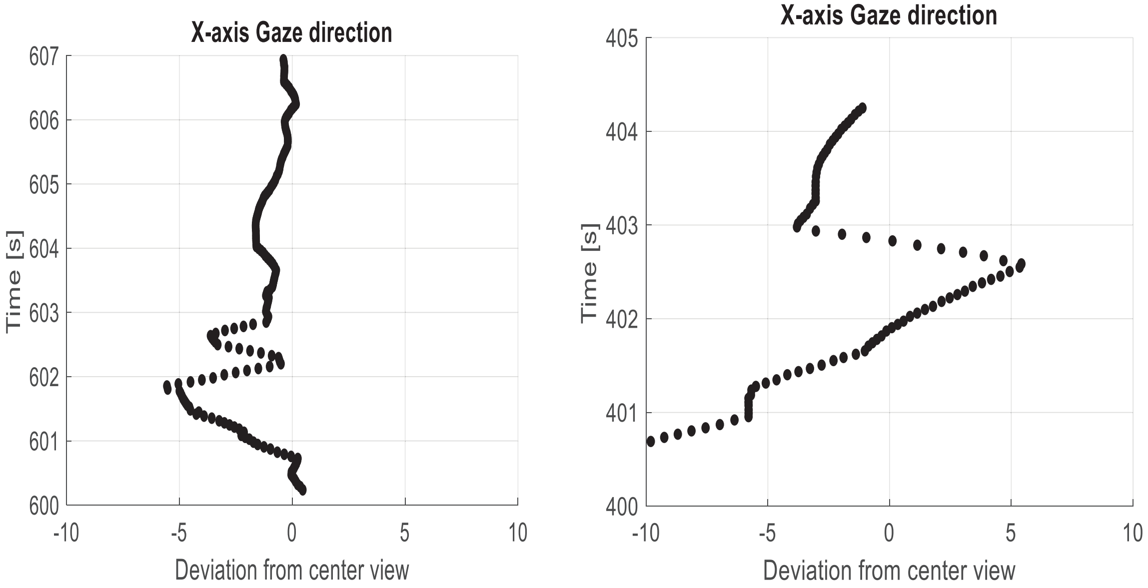


Figure 5-6 Reaction time progression over the popup incidences

Figure 5-6 shows the progression of the average reaction time of all ten subjects. From the figure, reaction time improves (as shown by mean and standard deviation) as the game progresses and deteriorates towards the end of the task. The popup incidences in the middle (popups 6, 7, and 8) had the quickest reaction time while the last incidence reported the worst performance, compared to the average of 3 s.

5.3.2 User gaze tracking

As mentioned earlier, the experiment was inwardly recording eye gaze as the user interact with both pop-up and game elements. The results below show gaze direction progression overlaid on to the conceptual scene setup shown in Figure 5-1. This is done to reveal tendencies of fixation or scanning the environment around the objects of interest. Gaze direction results are as shown in Figure 5-7. The figure show scatter plots of gaze direction (x-axis) of the driver, 5-7 seconds prior to a button-press. In the figure, the x-axis of the drive path (region of interest) ranged between -5 and 5 from the center view. Center view (zero point) represent the position the gaze would make in VR environment if the driver gazed straight into the environment. From the result, the user's gaze is actively engaged in the road environment both in the left and right side of the travel lane. The strength of the scatter plots (concentration points) reveals gaze fixation points, instances when there is an object of interest in the scene, while weak scatters are during gaze movement (scanning of environment or transitioning to the next object). Two distinct patterns in the gaze information are identified as localized search and scanning pattern.



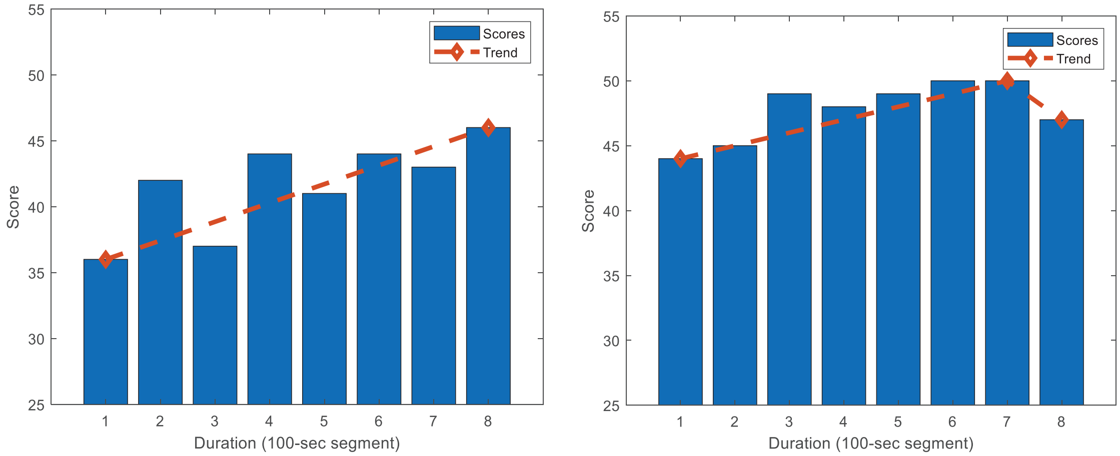
a) Focused visual attention b) Gaze scanning of the drive path

Figure 5-7 Gaze behavior derived from different objects

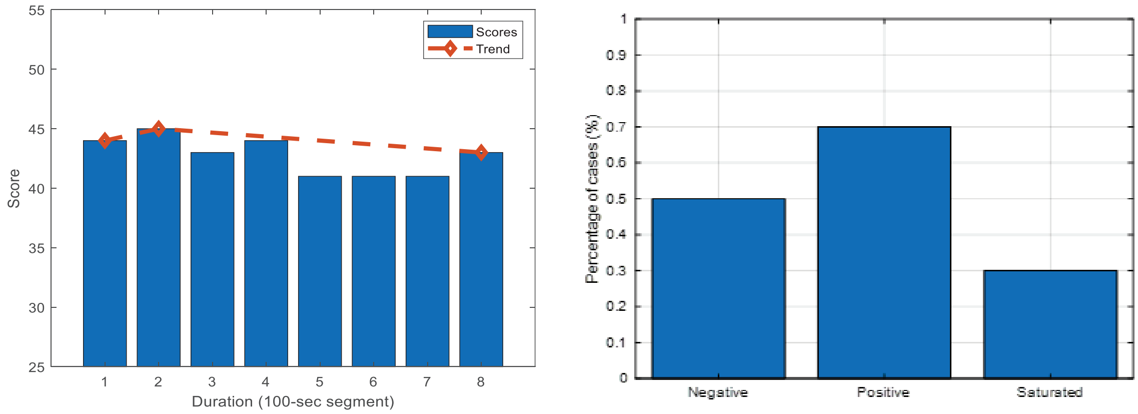
5.3.3 Score profiles

5.3.3.1 Intercepted objects profile (IOP)

Figure 5-8 shows the intercepted AR-Game elements (score) distributed in a 100-second interval (segment) from the start to the end of the simulation. Each duration represents a period in which 50 elements were spawned in the drive scene and the score is the cumulatively spawned objects. The accumulated scores have direct relation with user game interactions. After initial learning of the basics, the scores are expected to raise to a level allowable based on user's hand coordination skills. The results show a general profile of scoring progression, what we are referring to as intercepted objects profile (IOP). Three distinct profiles/patterns were observed as follows: a learning phase (positive gradient), saturation phase and a decline (negative gradient). This is highlighted in the Figure 5-7(a)-(c) using trend lines. The overall percentages of trends are shown in Figure 5-8(d). From the figure, 70% of the users showed a positive gradient, while 30% of users had a saturated trend. A declining trend was noted in half (50%) of participants.



A. Positive gradient B. Positive gradient with saturation



C. Constant gradient (saturation) D. Prevalence of trends among participants

Figure 5-8 Score progression and trends for different profiles

The phases are generated after observing the data from all users. Any extra testing of subjects conformed to the three phases and did not provide new information. The significance of each of the profile is discussed in a later section. Figure 5-9 shows percentage score of the drivers for the entire course. The figure shows an average scoring of 83.4% verifying the playability of the game to a satisfactory level.

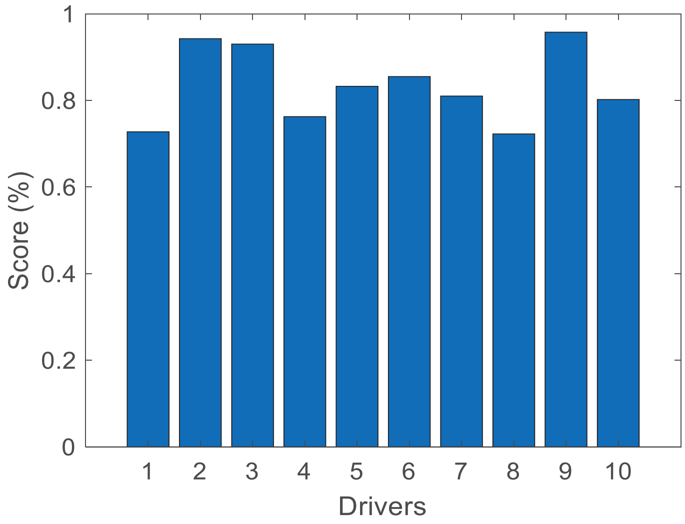


Figure 5-9 Overall intercepted objects (Scores)

5.3.3.2 Missed objects profile (MOP)

Similar and opposite to IOP, missed object profile (MOP) is significant as a pointer of the reasons for a missed object/errors. As with any gaming engagement, the rules for loosing are equally important and telling. In the game, a missed object is reported as when the paddle did not intercept the game element. MOP is formulated by plotting deviation index (distance from paddle to the target game element). This information is also tied to respective spawn point to formulate a profile. Deviation index is calculated as shown in Eq. (1) below.

$$\mathrm{I_{dev}} = |\mathrm{missed\_obj_i} - \mathrm{paddle\_pos}| \qquad (1)$$

where i represent the spawn position 1:5. Paddle_pos in this case represent the current position of the paddle and missed_obj represent the position of the currently missed object.

Deviation index, I_{dev} is given as the absolute separation distance between the paddle and the spawned AR-Game element. For each of the spawn point 1-5, corresponding average deviation index is logged and is shown in Figure 5-10. From the result, deviation increases as the object moves from the middle "U-shape" around spawn point 3 (drivers center view). The deviation index standard deviation error also increases from the center spawn point.

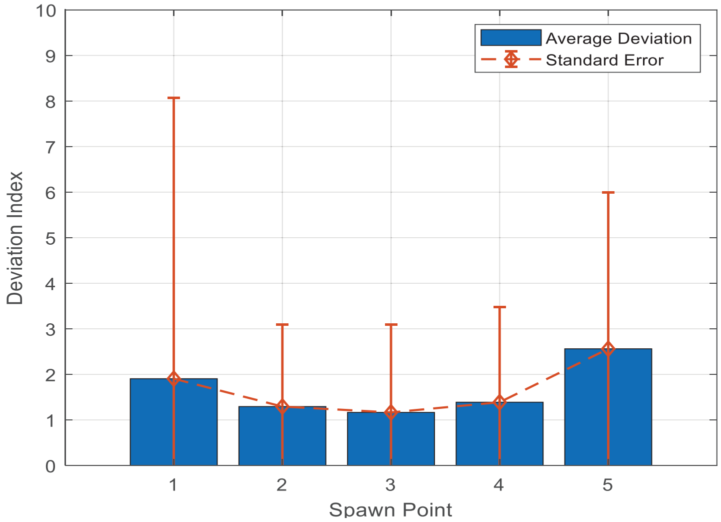


Figure 5-10 Missed objects deviation index.

5.4 Discussion

The aim of this work was to investigate the use of games in an autonomous car environment. To this end, we sought to gather driver behavior and tendencies that are useful in inferring level of engagement and driver state. The investigation sought to answer the question of what the effects will be of engaging in a simple controller game in an AV environment. We designed an AR game inside a driving simulator to analyze driver's engagement with game elements and staged pop-up traffic. Similar researches had no agreed upon standard of reference or evaluation scheme with more emphasis falling on design of approach [31], [69]–[71].

5.4.1 Recognition time and visual search

In the experiment, recognition of popup objects was compared between three engagement levels: no task, watching a video clip, and gaming tasks. The results are shown in Figure 5-4. The means for all the tasks were statistically significant ($p=.0213$, $\eta2 = 0.2081$). Of the two tasks, game was the slowest in recognition time, making it an ideal test ground for investigating the tradeoff between engagement and road monitoring. An important observation is the interquartile ranges of the tasks evaluated. The tasks had an IQR of 0.09, 0.2, and 0.07 s for No-Task, AR-Video, and AR-Game, respectively. This suggests that the AR-Game driver has a consistent RT compared to other tasks that fluctuate with attention shifts. The overall recognition time for all subjects yielded a reaction time of 2.9 s, which agrees with the findings of other researchers [17], [72]. The findings suggest that a driver engaging in an AR-Game would not be impaired by the gaming elements in recognizing threatening scenarios. On the contrary, it might help in maintaining vigilance. As seen in Figure 5-6, reaction time improved with time as users got used to the control mechanism and deteriorated towards the end possibly due to fatigue or lost interest in the game.

As far as takeover time is concerned, the literature review suggests no difference in performance with visual-loaded or cognitive-loaded secondary tasks [16], [32]. The main effect has been reported on metrics like time-to-hands-on-steering, time-to-eyes-on-road, amongst others [17]. These effects point to the mode of task presentation and interactivity as opposed to loading. From the literature and the comparison of tasks with no task, we assume that multimodal secondary tasks would not alter the recognition of hazards.

In addition, we explored a potential advantage of AR-Game, focusing the visual-search and patterns of the driver to different sections of the road. From Figure 5-7, we identified two visual search patterns: scanning and localization of the visual search. As objects are populated in the drive path (popup traffic and game objects), users' gaze reacts to each item. If the objects appeared within the same region, gaze fixation was noted in-stead of dispersed gazes while scanning. The two patterns identified above represent cases where the user shifts his/her focus to interact with objects. Authors [73], [74] reported that the driver's gaze is dispersed in the environment than manual driving for ADS. As opposed to a dispersed gaze, the results presented in the paper follow a systematic and focused transition from one object to another.

We confirmed positive tracking of AR elements that can be applied in refining the users' gaze to relevant information along the drive path. At the advent of self-driving cars, highlighting personalized content that the user is most intrigued by or relevant information outside of the car environment, such as traffic signs, would be an added advantage. Researchers have linked gaze wandering with boredom and lost interest [75]. In this paper, we have only tracked the progression of the gaze to ascertain the way users react visually to objects. Further analysis would be needed to ascertain cases of lost interest in the gaming activity using gaze information.

5.4.2 Score profile as engagement model

We managed to introduce and control gaming elements in the driving path to reduce the monotony in the driving scene. The overall score for the drivers is as shown in Figure 5-9. The overall percentage score represents individual control skills which reflect the ease of game control and interaction. All drivers had an average score of 83.4% and a minimum of 72.3%. Game score progression was theorized to reflect the user's engagement which is related to driver state. Considering the monotonous scene employed in the setup, the driver is only engaged with game-control or road monitoring. From this, missed objects will arise from loss of focus or shortfall in hand coordination skills. Consequently, as the participant engages in-game control, the progression trend will highlight the participant's engagement level. The intercepted object trends in Figure 5-8 show how the user interacts with gaming elements and indicates engagement as either enthusiasm, saturation, or declining interest.

Considering this is a game the users have never encountered before, a learning phase is expected at the onset, followed by either a decline or sustained scoring depending on the user's impression of the game. A positive gradient trend is indicative of an aspect of learning as the game progresses. This was present in 70% of the drivers new to the simulation. The saturation trend would indicate users who have learned the control scheme and actively perform at personal peak allowable within the constraints. This was majorly present in the gamer group, with a prevalence of 30% shown in Figure 5-8(d). The trend is sustained in cases where the user enjoyed the game or gave way to a downtrend. A declining trend was reported in 50% of participants towards the end of the experiment. This agrees with the deteriorated recognition time in Figure 5-6 towards the end of the experiment pointing to fatigue or lost interest. A transition from positive to negative gradient would be ideal for introducing levels and or other gaming elements to keep the user engaged. If fed to the system, the trends identified in the result would add to the pool of feedback information of the current state of the driver. This way, the system will have a form of contextualization of the state of the driver.

5.4.3 Game design consideration

As noted from Figure 5-10, AR-Game elements on the sideways were easily missed compared to center objects. This agrees with the results from different authors on the anisotropic perception of object size, distance, and positioning in a VR environment [71], [76]. From these results, the deviation index increases as the position of the playable object depart from the center. The "U-shape" error pattern is a critical consideration in the enjoyment/challenge of AR elements. It points to the hurdle that must be considered in terms of 3D world reconstruction due to visual perception and biases in the human brain. Careful consideration of the playable/interactable environment is recommended.

Various research inquiries have been made touching on VR usage and interfaces in cars [47], [77], [78]. The key points are on collision with constrained spaces, social acceptance of

HMDs, control mechanism, amongst others. From the proceeding pilot test, we recommend a limited application of full-body control schemes. This would include tasks that require standing, sways/body rotations, raised hands, amongst others. The current game did not require any full-body activity, but inadvertently, most users were observed to exhibit body sways and shifts that inherently alter the center of gravity. In a moving car, the interplay of user head motions has been cited as a potential source of discomfort [79]. Besides this, moving body parts increases the chances of collision with physical barriers.

In the foreseeable future, games will become an integral part of the in-car experience. A car in motion is a potent source of somatosensory information that would significantly enhance the game experience if adequately integrated. At present, video games are predominantly audio-visual in delivery mode. The inclusion of car movement dynamics will add to the realism of the experience. A primary consideration is safety. In the face of an accident and the user is immersed in a disconnected game from a developing road situation, the physiological unpreparedness might be too high. The way to think of this is an airplane on a nosedive with no one to issue a brace-for-impact warning. From this paper’s discussion and consideration points, we recommend that games in cars take on an augmented approach to build on the drive path environment to maintain situational awareness irrespective of the automation level. An obscured drive path would need an intervention mechanism to build awareness.

5.4.4 Limitations

The experiment employed a 3D-VR game prototype in place of a real driving environment. Real driving scenario would be preferable, but the AV technology is not fully matured, a substitute of VR has been utilized to give insights and design for future development. The limitation in this has to do with the lost sense of danger which might impact generalization of the recognition time. However, intuitively, in a real threat scenario, threats would be processed with higher priority not lesser. Motion sickness manifesting as mild eye fatigue was reported by one subject, but the greater majority did not have any physical discomfort. The test subjects comprised of a young population as mentioned. In case of an older test subjects, the effects of VR usage might be more pronounced.

The design of experiment is also not exhaustive, as a proof of concept, the study was conducted with limited test subjects, targeting university students in a controlled environment. Additionally, the setup considered a traffic scenario with no competing stimuli. Further investigations will be conducted incorporating diverse groups with variation of stimuli in a real-world environment. Studying behavior in a real-world environment with near-natural stimulation of physical car movements; acceleration, braking and other dynamics, will offer important information for design of automated vehicles and infotainment systems. In the next phase of the study, 3D-VR/AR game will be tested in a real-world with a moving car following the recommendations derived from this test.

CHAPTER VI: IN-CAR ENTERTAINMENT & ENGAGEMENT

6. IN-CAR ENTERTAINMENT AND ENGAGEMENT

6.1 Introduction

Autonomous vehicles (AVs), though in active development, is being explored through different conceptual designs by automobile manufacturers. A general consensus with researchers and automakers is on the foreseeable transition to car-of-the-future, wherewith a remodeling or finetuning of the current cars will be a necessity [80]. Conceptual designs have been explored with suggested reorientation of the interiors to have forward and backward seating as noted by [81]. Adjustment of window size has also been proposed to reduce on production cost [51], [25]. Different automobiles have envisioned concept cars of the future. Mercedes-Benz® Vision AVTR, Nissan IMS, Audi AICON, Toyota concept-I and many others are forecasting the needs of the users when full AV is achieved. A constant theme present in all the manufacturers is availing an environment for the driver/user to work, communicate, be entertained or even nap because, at the advent of ADS, the driver is relegated to a passenger.

One way such environment in a moving car is by use of Virtual/Augmented/Mixed reality (VR/AR/MR). To date, VR, AR, and MR are a promising venture that have been applied in education, automotive, robot operations, surgeries to name a few. Immersive experiences have been proposed by developers [25], [38], [82] to reintroduce artificial experiences to the car user. This would cover games, holographic meetings, remote working environment, avatar conferencing, amongst others. In this form of application, the user is supplied with visual and other haptic contents that is either synchronized or disconnected to the present physical reality. As a use-case, a user playing an immersive in-car game with a Head Mounted Display (HMD) will be interacting with game elements visually and experience the dynamics of a moving car. As such, there are two distinct realities (physical and cyber) that will either be competing or working together. The disconnect between physical and virtual reality has been showed to increase discomfort (motion sickness/cybersickness) particularly while using HMD. In a moving car, reading a book and or other passive activities have been shown to increase discomfort manifesting as motion sickness effects. With the introduction of VR in the car, special care ought to be accorded in view of user experience.

In this work, borrowing from previous research, we propose to explore further the usage of in-car VR as an entertainment modality. Compared to the previous research, the current inquiry goes further in investigating in-car VR, utilizing game and video tasks, the two most engaged in pass-time activities and explore the physiological aspects of engagement using eye data and electrodermal activity (EDA) levels for each engagement. Further, we explore the use of road monitoring for pop-up objects, theorized as monitoring for hazardous along the drive path. The recognition/reaction time is recorded for analysis and comparison.

In the study, we investigate the feasibility of performing four distinct tasks; no task/baseline, game task, video clip task and mixed video and game task, performed in VR from a moving car environment. For analysis, we measure body sways, eye gaze information, pupil size variations and SC of tasks. The research at hand therefore seeks to inquire on the following

a. Evaluate user's engagement with different in-car VR elements. This will prove useful in identifying suitability of VR contents and their engagement levels in a car to enhance user experience.
b. Investigate user's recognition of threatening driving scenarios while engaging in different virtual tasks. This will be indicated by the time taken in accurately pressing appropriate button.
c. Investigate the influence of content design on posture (head movement) in 3D space.

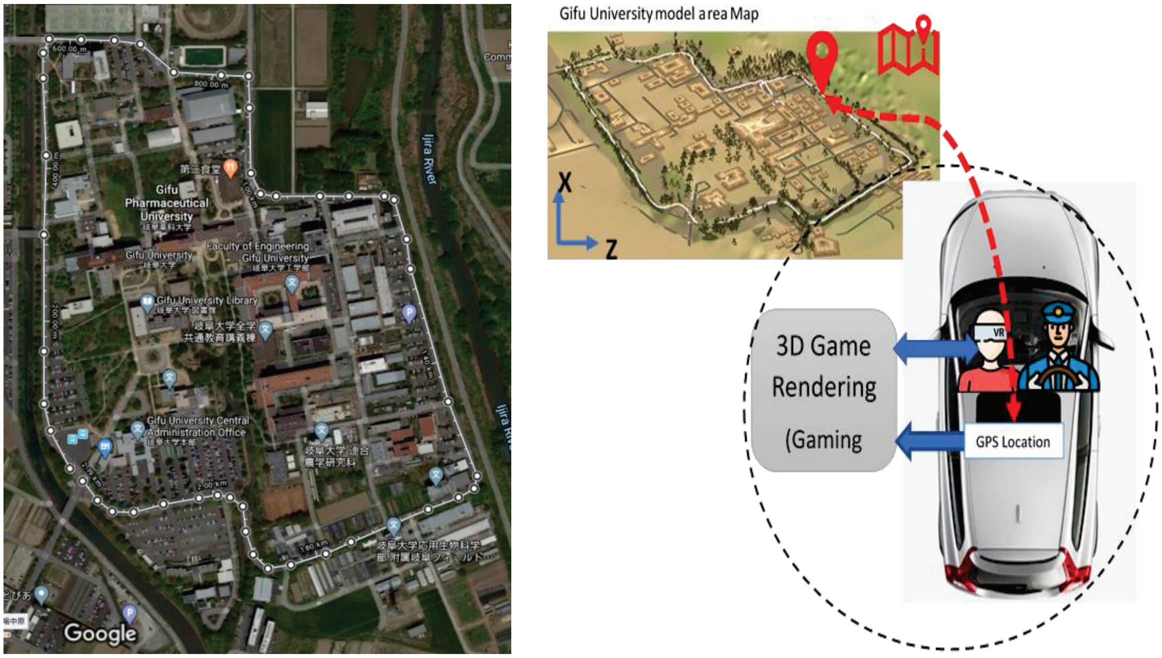
6.2 Methodology

6.2.1 Driving simulator

We designed a custom car simulator scene with Unity 3D game engine for the proposed driver analysis. The VR content was designed to be experienced by passengers in a real-world moving car as opposed to a previous design that targeted a parked car moving in a straight line [83]. The car in use was a Subaru Stella Matic, with a displacement of 600cc, with no special relaxation features in place. The experiment was conducted in the premises of Gifu University, Japan. The area covers an approximate distance of 2.5 Km as shown in Figure 6-1(a). The area map was selected as a test ground as it featured at typical road conditions in Japan albeit with a reduced drive speed. The campus has a speed limit of 20 Kmph, six speed bumps, three barrier gates for entrance and exit, and six crosswalks around the perimeter. The environment is relatively flat, with one way asphalt road. To avoid traffic delays, most of the experiments were performed on weekends.

The major building blocks of the setup are shown in Figure 6-1(b). The setup involved the following units: a gaming PC and HMD for rendering the virtual scene, a GPS tracking device(s) for localization in the virtual map and physiological recording unit, palmar EDA.

Physical car rotation has been reported to interfere with VR rotation in previous studies. As a remedy, different authors opted to either preconfigure rotations or have a third party orient the view [42], [84]. In this work, the virtual vehicle’s rotation is calculated by the game engine. However, when the car rotates, the movements are perceived by the HMD inertial measurement as head movements. To correct for this, we availed a user-controlled correction using joystick (DualShock 4 Wireless Controller) buttons. The in-car experiment setup is illustrated in Figure 6-2. Wireless joystick controller is connected to the laptop rendering the simulation.



a). Actual Gifu University map b). In-car VR conceptualization

Figure 6-1 In-car VR setup and conceptualization

Figure 6-2 Experiment setup showing in-car test subject in the front seat and the driver for the project.

GPS was opted for to avoid the processes for signal acquisition from OBD of the car. In this case, the position of the virtual vehicle is controlled by the position received by the actual car. In the scene, we utilized multiple GPS sensor arrays to correct for position error, with an update rate of 1 Hz. The received latitude and longitude coordinates were fed as the (x and z-axis) target move position in Unity 3D. Y-axis (height from ground) was constant in the scene, giving the virtual vehicle a hovering-like motion. The resultant sample data is shown in Figure 6-3.

The rotation towards the target position was calculated to effectively orient the virtual vehicle in the y-axis only. Instead of a closed car environment, we opted for convertible type of vehicle that does not occlude the 3D scene view and gaze. We experimented with 3D models of convertible cars but opted for a 3D model of starship with no outer covering. This was because of hovering movement maneuvers employed in the game which was unlike a typical car movement.

During design, we noted that scenes with elaborate details like houses and road markings, though desirable for context, were incongruent when the VR car collided or deviated from the markings. This is expected to be an issue with GPS accuracy. As a work around, we reduced scene details and utilized a checkered ground to maintain a metric for movement.

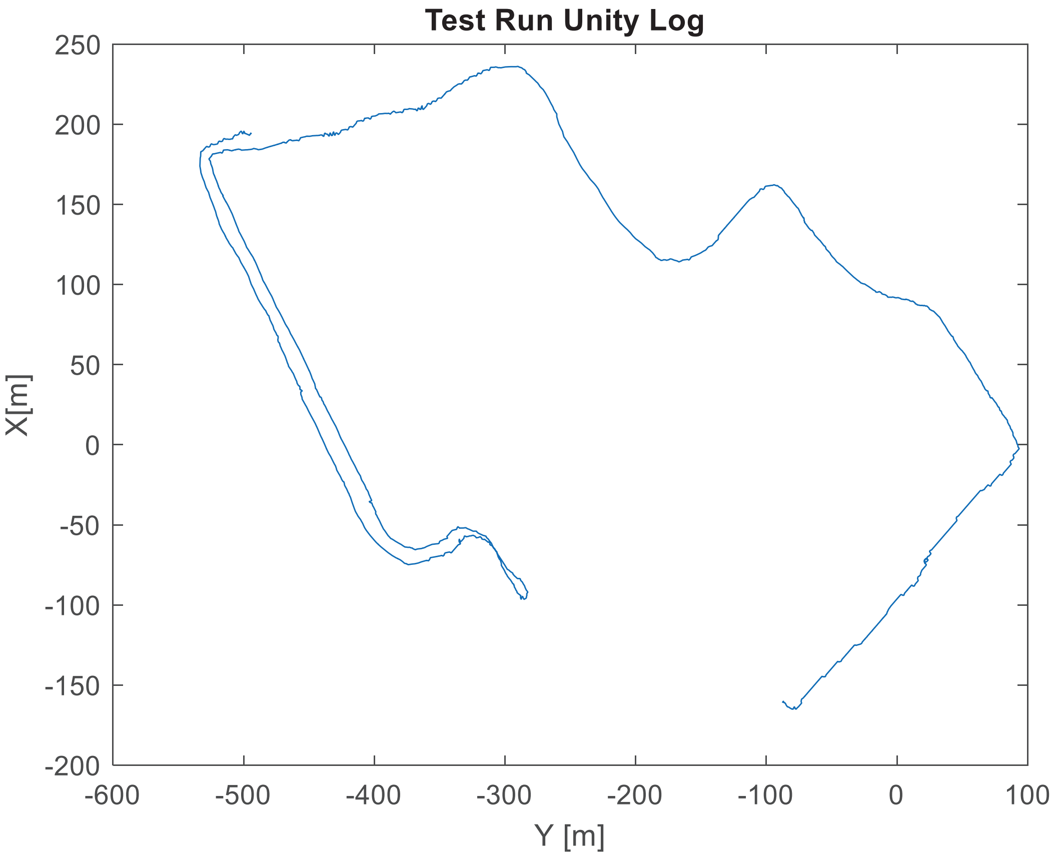


Figure 6-3 Sample GPS data

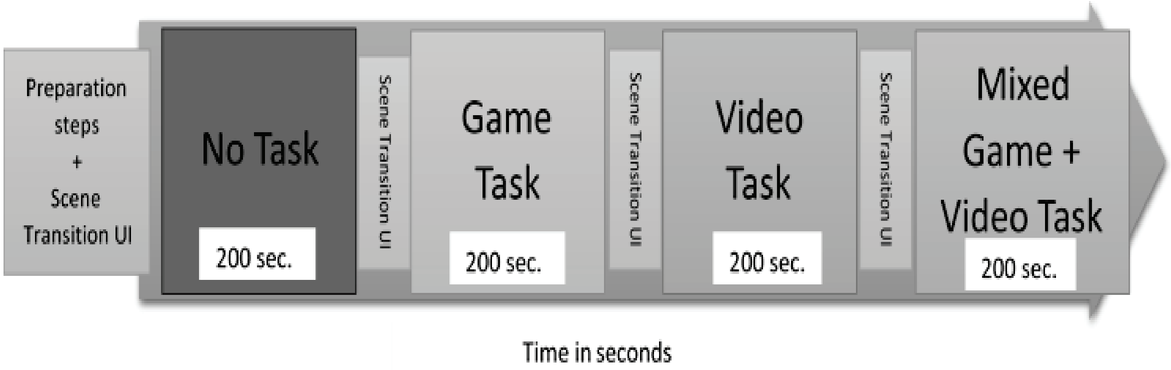


Figure 6-4 Unity 3D content progression overview.

6.2.2 Game mechanism design

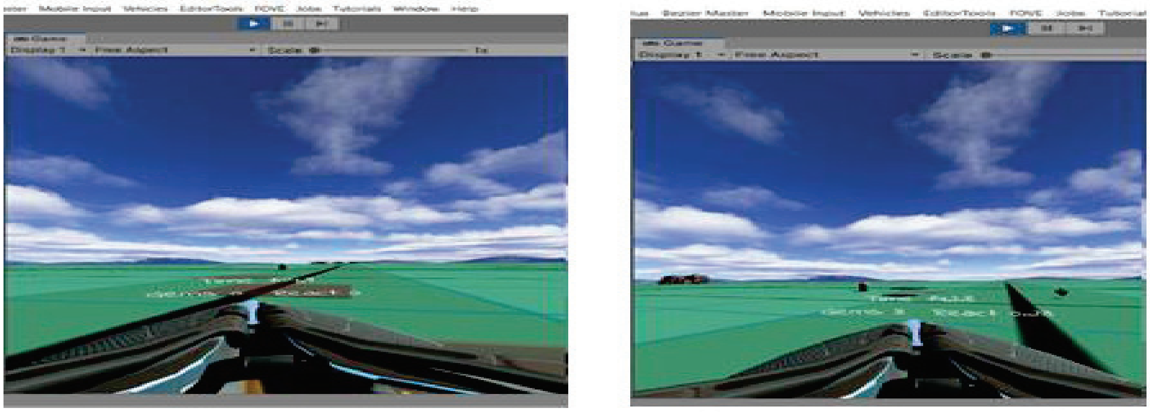
The target of the paper is to evaluate passengers/driver engagement within-car VR elements. The paper introduces gaming in car as a pass-time activity that will improve engagement as well as offer entertainment. As such, a 3D driving course was designed in unity featuring the list of activities shown in Figure 6-4. To investigate the impacts of engaging with each of the activities, we include pop-up objects that are random spawned in the scene. The user is required to click a specific joystick button to acknowledge recognition. Sample scene for the different tasks is shown in Figure 6-5.

6.2.2.1 No Task

As the name suggest, there was no extra task rendered in this phase. This was meant to get the user accustomed to the 3D scenes, capture the natural response and baseline of physiological responses. Besides the user reaction of popup objects, the user was also required to orient the VR to a forward-facing direction using joystick.

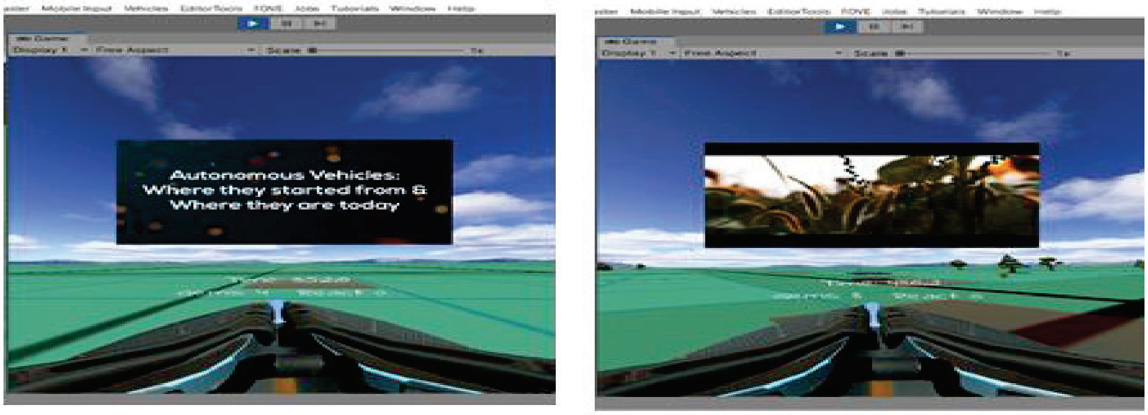
6.2.2.2 Gaming task

On the game setup, the driver is actively engaging with elements on the road in while monitoring for pop-up objects. A controllable paddle object (player) is located a few meters from the cars' position which is clearly visible by the user. The paddle moves with the virtual vehicle and is controllable along x-axis by the user. As the car moves autonomously, collectible objects are spawned ahead on the drive path by the gaming engine at an interval of 2 seconds. When the controller paddle (Unity 3D game object) collides with the mesh of the spawned object, a score is registered (intercepted) and the contrary for missed object. This is made possible by Unity 3D physics engine that checks for interaction of game objects.



a) No Task

b) Game Task



c) Video Task

d) Mixed Task

Figure 6-5 Sample scenes of different tasks

6.2.2.3 Video Task

We propose to set up 2D video on the drive path in such a way that the driver can transition from video to road monitoring effortlessly. This is achieved by projecting the contents into the environment as opposed to having the video player located in a cockpit. With this setup, the video is rendered in the upper part of the drive path, leaving enough window for road monitoring. The setup is meant to reduce time taken to have eyes on the road. The setup is as shown in Figure 6-5(c).

In this case, the video is rendered on a Unity 3D texture material located at 200 meters from the camera position. Since the camera in use is a VR, head rotations affect the position in the scene affected the positioning of the video. We utilized an instructional video that requires more attention. In this task, no other content was issued apart from popup objects.

6.2.2.4 Mixed (Game and Video) Task

In the mixed task, an entertainment video (music video) was played on the rendering texture as described in Video task. The video was meant to be casual in its utility affording the users a choice of engaging with music video as they play a game. In this scene, the users played the game, engaged with video, and scanned the environment for popup objects, simultaneously. The setup is as shown in Figure 6-5(d).

6.2.3 Evaluation parameters

In this experiment, we propose to utilize objective data measures to quantify or describe engagement models. To this end, subjective methods like questionnaires were sparingly utilized, albeit in the design and feedback of experience. As such, no questionnaires findings are reported. We rely on physiological measures, pupil size and EDA response, to infer the engagement.

6.2.3.1 Physiological measure of engagement

In the experiment, eye tracker and EDA were used as an objective measure of user's engagement model with the scene and activities therein. The pupil radius and gaze information were recorded from FOVE HMD while as palmar EDA was collected from the less dominant hand of the user. Processing of cleaned pupil radius data was performed using custom built MATLAB functions.

6.2.3.2 Posture and head movement

Posture and improper body movement is a concern in a car environment, the effects are even more stringent in the use of VR. In a situation where the real-world is obstructed, postural disorientation is bound to happen. Several authors have attributed car discomfort with improper postures that correspondingly produces unnatural body sways.

In the current setup, we investigate which content encourage posture adjustments and movements. 3D position of head movements is recorded from HMD and utilized for analysis. The indices of interest are the lateral and transverse directions with reference to car movement. Transverse is HMD y-axis which correspond to physical cars' forward direction. In 3D VR, this was registered when participants leaned forward or backwards. Lateral movement corresponds to HMD x-axis and results from head rotations.

6.2.4 Experiment protocol and participants

The experiment was conducted both in a car environment as shown in Figure 6-2. GPS readings were parsed to game engine using serial communication as soon as the location was received. In addition, the user had to keep orienting the view to forward-facing direction. The participants experienced the contents in the order listed in Figure 6-4.

Students comprised the participants in the study and were recruited following approval from the relevant ethics committee. Real-life driving or gaming experience was not considered in the current study. A preparatory scene was presented prior to recording of data. In this test, the subjects were introduced to the controls and buttons as well as the general objective of the experiment. No incentives were offered to the subjects. The volunteering subjects were instructed to stop the experiment in case of any motion sickness effect.

Each subject's gaze information, button presses, scores and interaction with game elements is logged in an excel file for further processing. Each recorded session lasted between 10-15 minutes for all subjects. Data analysis was performed using MATLAB® software.

6.3 Results

6.3.1 Reaction time

The following section describes the results obtained from the experiment. The reaction time associated with individual tasks is shown in Figure 6-6 with * indicating groups with statistically significant difference between the groups ($p <= .05$). From the figure, no-task had the best reaction time (mean = 1.06 sec, SD = 0.86) followed by Video-task (mean = 1.38 sec, SD = 1), Mixed-task (mean = 1.48 sec., SD = 0.94) and Game-task (mean = 1.49 sec., SD = 0.88), respectively. The interquartile range of No-task was considerably very compact as the users did not have any additional task. The remaining tasks had a comparatively similar recognition time as indicated by the box plot and quartiles. Of the three tasks, video task had a lower reaction rate owing to the hands not performing any immediate operation compared to game task.

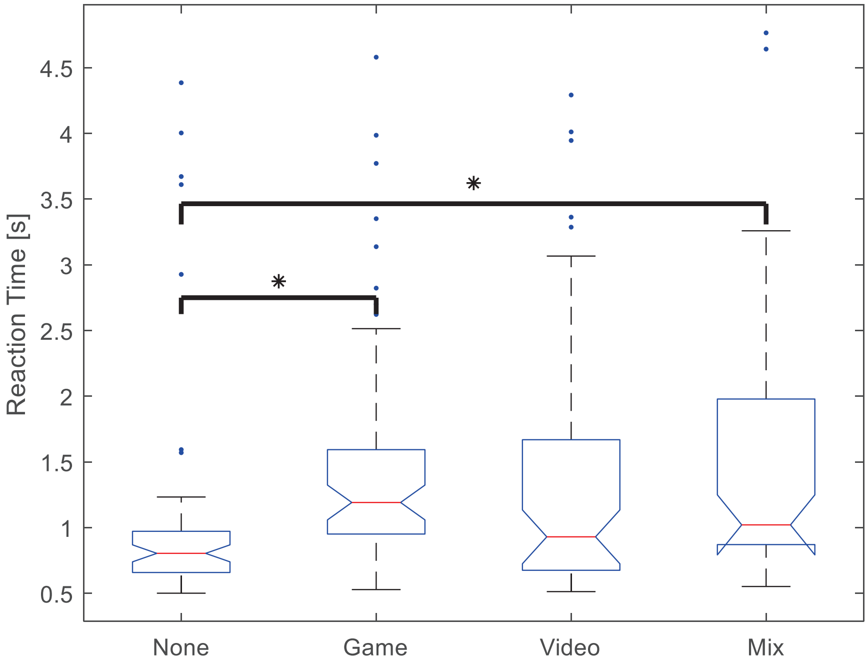


Figure 6-6 Popup object reaction time of all subjects

There was a statistically significant difference between groups as determined by one-way ANOVA (F(3,231) = 2.75, p = .0437). A Fishers' (least significant different) post-hoc test revealed that the means of game and mixed task reaction time were statistically significantly different (p = .0126 and p = .016, respectively) compared to No-task, as highlighted in Figure 6-5. Post-hoc test of the means is shown in Table 6-1. From the table, video task had no significant difference to no-task (p=.06).

6.3.2 Engagement model from physiological signals

The experiment relied on physiological signals to infer engagement, i.e., using pupil size variation and EDA. Figure 6-7 shows sample data of pupil radius and palmar EDA readings recorded in the experiment. In the figure, colored patches represent each of the tasks under evaluation. In the case of pupil radius, a moving average filter has been applied for visualizing the resultant signal. Each of this signal is analyzed in the next section for all the participants.

Table 6-1 Fisher's post-hoc test P-values for determining association between group means

Group comparison		**Mean Estimation**	**95% Confidence Interval**		**p-value**
			low	high	
1	2	-0.43	-0.77	-0.09	.01
1	3	-0.33	-0.66	0.01	.06
1	4	-0.41	-0.75	-0.08	.02
2	3	0.10	-0.23	0.44	.54
2	4	0.01	-0.32	0.35	.93
3	4	-0.09	-0.43	0.25	.60

NB: Group 1 – No task, 2 – Game, 3 – Video, 4 – Mixed

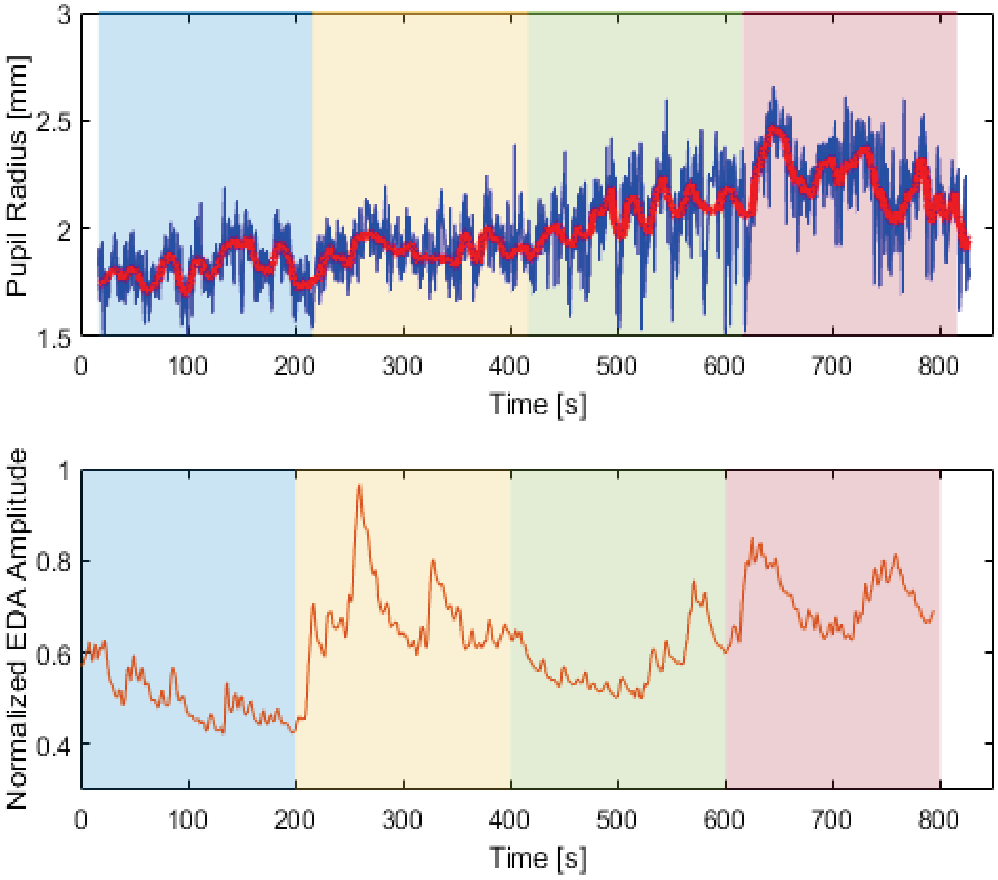
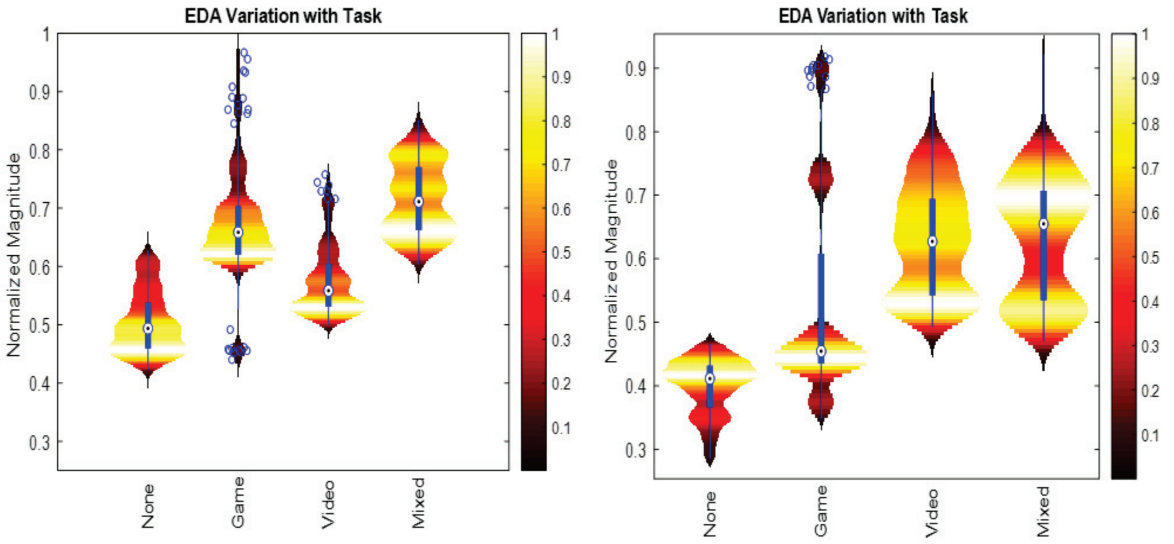


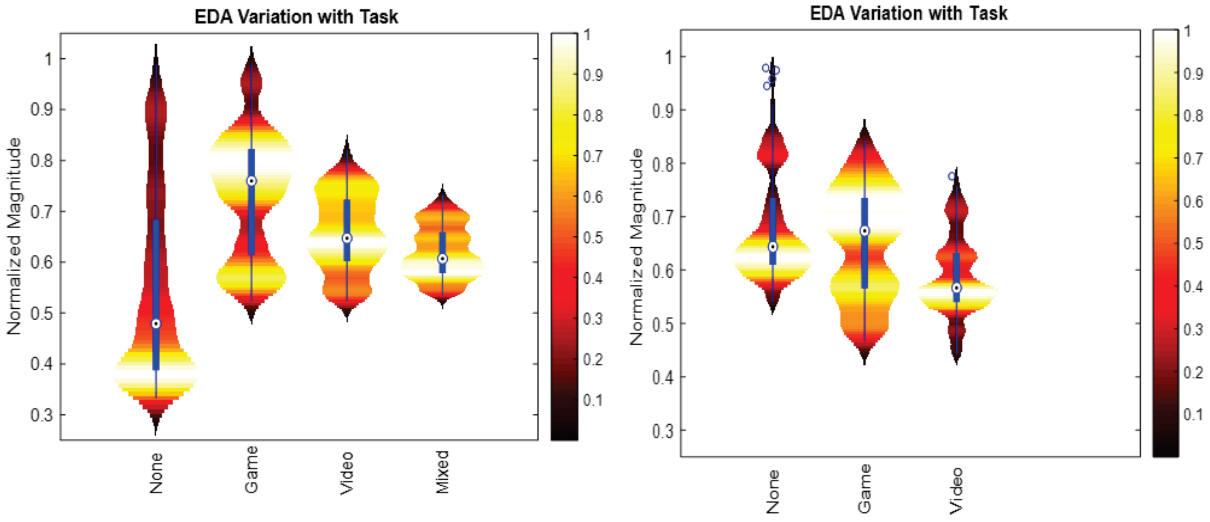
Figure 6-7 Raw pupil size and EDA readings from one subject in the car VR scene.

6.3.2.1 Palmar EDA

Palmar EDA was recorded for affective analysis of individual tasks used in the experimental VR setup. The results are plotted in violin distribution and boxplot to show density and other statistical parameters as seen in Figure 6-8. From the figures, different subjects produced different varying responses that have common trend as below. Individuals with increasing affinity towards the tasks shows a continual increment or at least a sustained reaction. Figure 6-8(a) shows a case where the user reported a higher engagement with both gaming task. Figure 6-8(b) on the other hand was engaged with the videos.



a). EDA activity with game preference b). EDA activity with video preference



c). EDA activity with declining engagement d). Activity of the user who quit the experiment

Figure 6-8 Sample EDA activity trends from different users

Figure 6-8(c) reported cases of discomfort with continued usage and the plots quantified the disengagement. In Figure 6-8(d), the user reported discomfort and requested to stop the experiment. A similar trend to Figure 6-8(c) is observed of declining engagement.

The average EDA response of all users considered in the setup is shown in Figure 6-9. From the figure, game tasks were more engaging compared to video task as seen in Mix and Game-Task distribution. From this, the tasks in use are verified to be engaging the users more than a no-task scene.

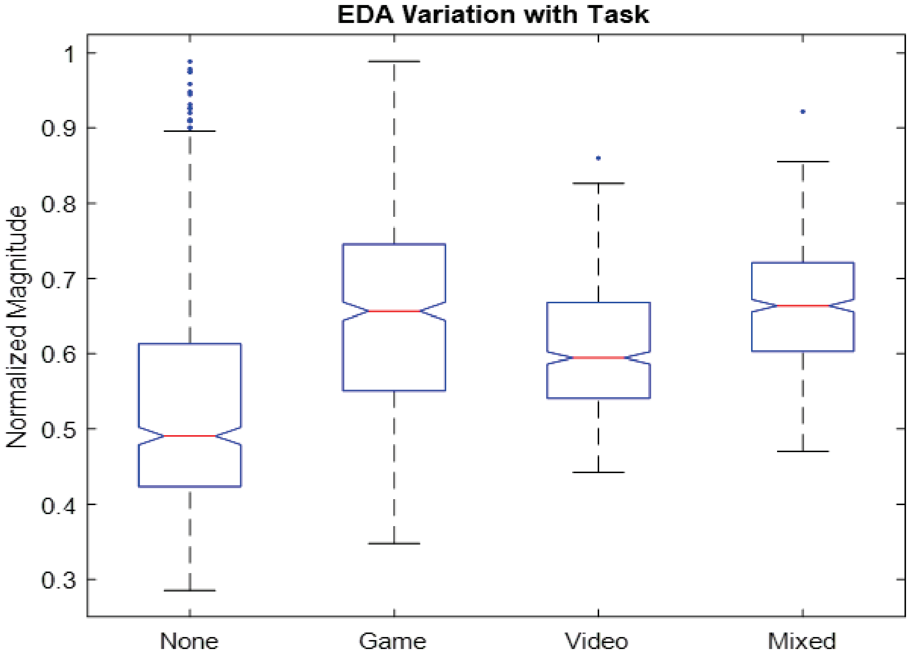


Figure 6-9 Average EDA activity for different tasks

6.3.2.2 Eye pupil size

In this experiment, pupil radius changed as shown in Figure 6-10. From the figure, No-task had the lowest pupil radius for all the participants. Pupil size thereafter changed based on the task at hand. There was a linear increment in size as tasks change. Particularly, a notable difference is observed between game, video and mixed tasks that have focus elements located at the same position. This would rule out accommodative response to the mental processing and engagement response. From this, there is a discernable engagement in the use of tasks.

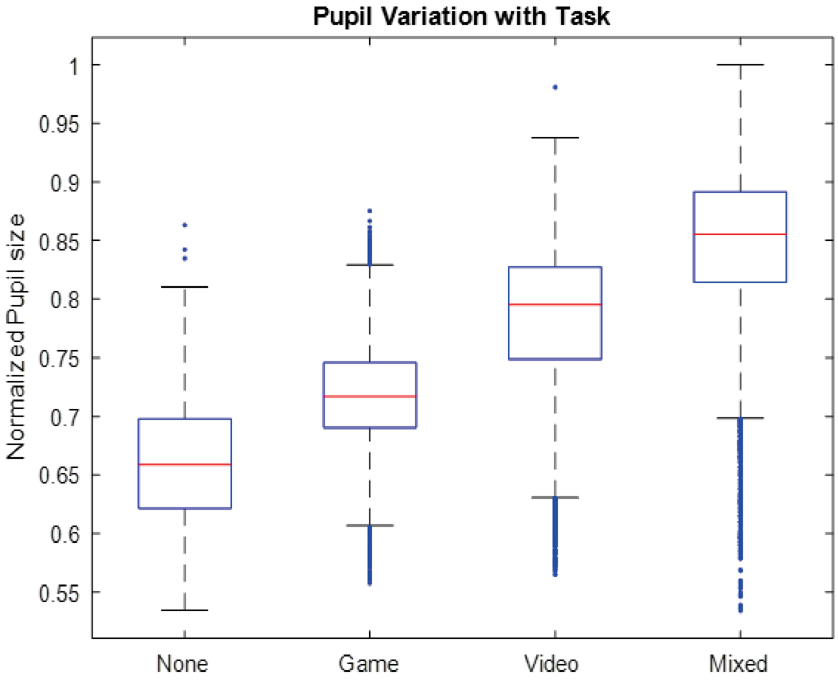
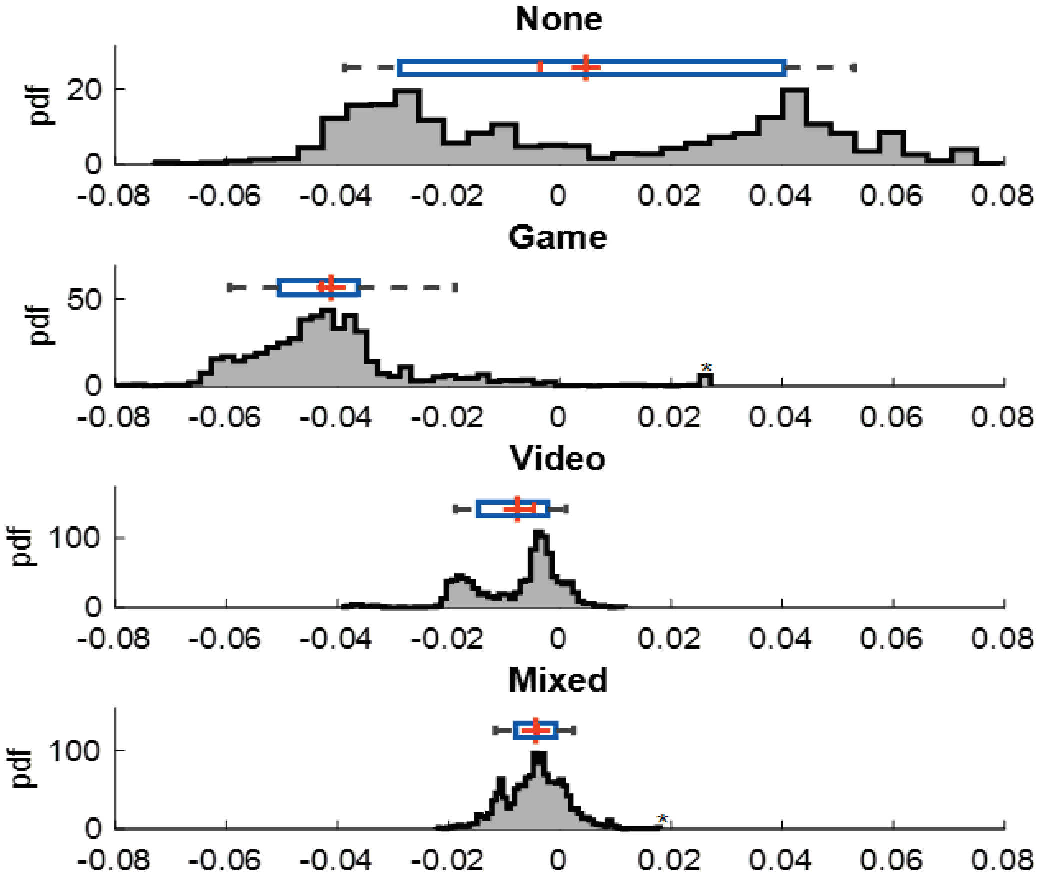


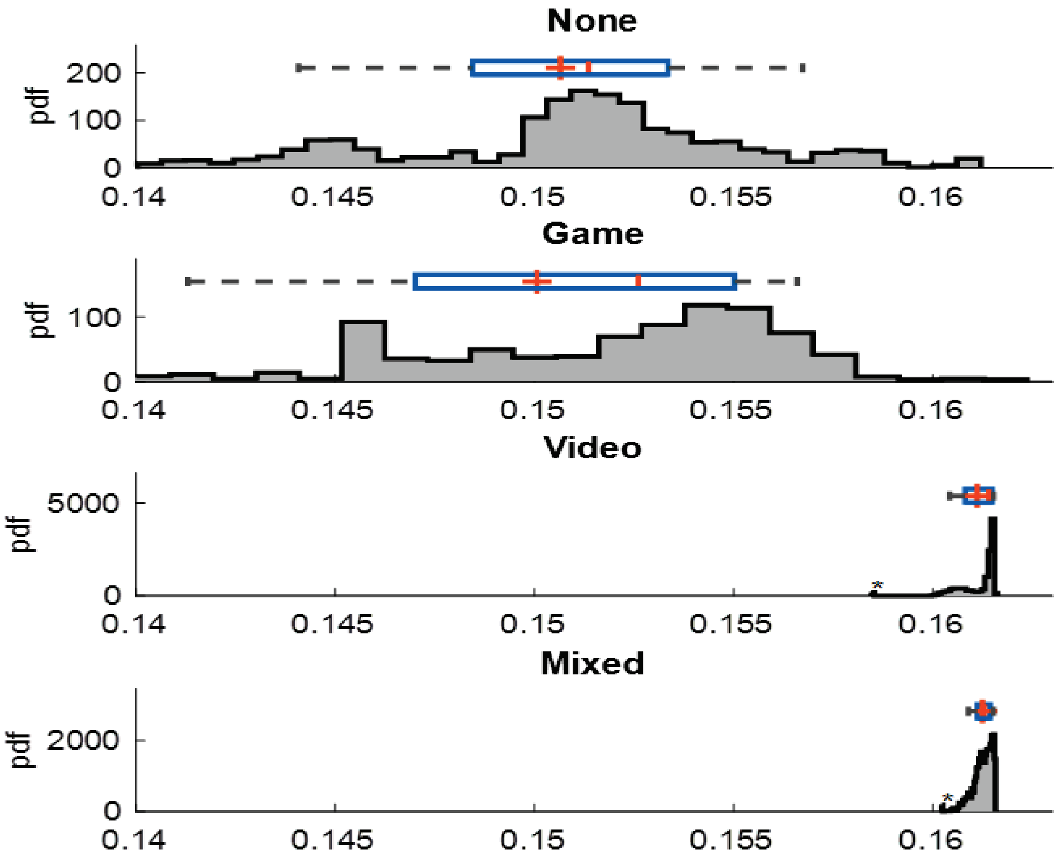
Figure 6-10 Pupil radius trends for different tasks

6.3.2.3 Posture (Head movement)

In VR usage, where the user can not properly tell the orientation of the vehicle from visual cues, can have a disorienting feeling. To address posture and avoid discomfort, analysis of head movements in VR use is needful. In this study, we recorded the 3D position of the head from the VR headset. Figure 6-11 shows the histogram of head movement in different task. An overlaid boxplot gives additional information as per the distribution of occurrences. From the results, when subjects were not engaged in any task, there were wide-spread lateral deviations compared to when there was an engagement task. From the histograms, use of video task encouraged postural adjustment as witnessed by a more compact interquartile range and peaks around the center as seen in Figure 6-11(a). Also, there was reduced backward-forward head movement, represented by a left skew in video and mixed task of Figure 6-11(b).



a. Lateral (HMD X-axis) direction



b. Transverse (HMD Y-axis) direction

Figure 6-11 Histogram of subject head movements

6.4 Discussion and Recommendations

The paper has explored different engagement modalities that are applicable in a car VR experience. We designed four scenes that are to be experienced in an actual car driving session and utilized pop-up events to investigate the impacts of recognition with each of the tasks. Specifically, this work was concerned with the content design, description of engagement (reaction time of popup events and physiological measures) as well as posture and head movements. Each of this focus area is discussed below.

6.4.1 Scene design consideration

User controls and manipulation of scenes has been linked with reduced discomfort [85]. This has been one of the motivating aspects for the usage of VR and MR in automobile designers since the artificially generated content can be manipulated [49], [50]. On the other hand, VR usage has been received with mixed reactions from users, as pertaining to motion sickness [23], [27], [43], [47], [86]–[88]. That said, the attainable possibilities in a properly executed in-car VR are tremendous as eluded in the following discourse. To merge the strengths of VR to a user-controllable scene, we employed gaming tasks, rotational control as well as video positioning in the scene to avail scene manipulation in the experiment.

The insistence on a good design cannot be over emphasized. Several recommendations have been made towards in-car VR. Scenes with minimal or no incongruencies are highly recommended. In the game design, we found that scenes with obstacles (buildings, trees) colliding with the users had an unsettling effect which is similar to what is reported in [41]. Owing to the localization method employed (GPS signals), virtual car location had a positioning error of ±2M from the current inroad position. The rotation and position error around road markings introduced further incongruencies. Incongruencies of car deviating from main road or misorientation were verbally pointed out as unsettling by participants. To mitigate this, reduced terrain details (building and road markings) were used. In place for motion information, a checkered ground was used which attained a contextualization for motion and direction.

Several researchers have investigated visualization and cue presentation in autonomous vehicles to reduce motion sickness. From practice, motion sickness in real cars is thought to be reduced when participants focus on an outside environment, in which case, visual and vestibular disconnect are reduced [89], [90]. In the design of the scene, we capitalized on an environment-centric design to emulate real-world practices. This was achieved by taking the engagement tasks outside the car, ensuring that the user is aware of external movements, though virtual, as he/she engage with entertainment task, simultaneously.

6.4.2 Engagement considerations

Disengagement has been identified as a course of present and future challenge to be facing autonomous drivers who will need to take over control [21], [22], [31], [67], [75], [91], [92]. The research explored in-car VR performing different tasks. This is proof of concept test applicable as an alternative infotainment system in a much-anticipated advent of AVs. In the experiment, we explored the engagement with different tasks in a car and evaluated the impacts that would have in monitoring for specific elements on the environment perceived as hazardous. We designed four tasks; none, game, video, and a combination of both, inside a driving simulator to analyze users' engagement with game elements and staged pop-up objects.

From Figure 6-6, the users engaging with no-task scene had a high recognition rate and this is desirable in a monitoring system. However, as posed in a previous experiment as well as literature review [21], [22], [83], [93], this state of monitoring with no external distractions is hard to maintain and is bound to manifest fatigue faster than other conditions. Thus, a more feasible mode of engagement is needed that will offer a tradeoff in vigilance as suggested in other tasks in review.

The average reaction time performance of subjects evaluated in tasks were as follows; No-task had the quickest reaction (mean = 1.06 sec., SD = 0.86), Video-task (mean = 1.38 sec, SD = 1), Mixed-task (mean = 1.48 sec., SD = 0.94) and Game-task (mean = 1.49 sec., SD = 0.88). One-way ANOVA found significant difference in the means of the groups (F(3,231) = 2.75, p = .0437). Fishers' (LSD) post-hoc testing indicated that game and mixed tasks were significant (p = .0126 and p = .016, respectively) compared to No-task. This was expected, as the hands are actively controlling a game and therefore reaction time is slightly delayed. From table 6-1. No-task had an average mean difference of 0.43 and 0.41 s. for game and mixed tasks, respectively. Video task had similar performance with no-task. Overall, the experiments' difference in reaction time was less than 1 second and therefore, the usage of additional tasks did not negatively affect recognition.

From Figure 6-9&10 that shows average pupil and SC activity, No-Task reported the least engagement. Game and video tasks exhibited higher engagement, but this depended on the user's preferences. The choice of either would be a preferential choice that is easily attainable. The experiment was conducted within 10-15 minutes of use and therefore, the engagement model may vary in continued usage, however, if the initial parameters are to be maintained, a method of capturing the user's attention can be introduced every time there is a decline in engagement. In other words, the setup avails an indirect measure of engagement during user interactions. This way, vigilance can be supported for extended periods of time.

6.4.3 Posture considerations

The research also sought to understand postural and head movement since the HMD completely occluded the physical environment. This was done using lateral and transverse head movements. No-task engagement mode had higher lateral and transverse head movements as shown in Figure 6-11(a)&(b). This may present as challenge in the usage of VR as excessive head movements and sways have been linked with car/simulation sickness [51], [79]. From Figure 6-11(a), no task had almost same transverse head movements as a game-task which is unconventional. From the design, the game is designed to spawn objects a few meters (20 m.) and the user was to scan the environment to guide a paddle to collect the objects. This way, deviations on x-axis are expected to be high in a game-task (as is the case) but not in no-task engagement. The other left explanation for this would be on the users undirected gazes wandering into the scene and terrain, which has been associated with boredom and loss of engagement [94], [95].

A striking difference is noted in a game compared to mixed task, which primarily had the same the same game setup. On the transverse direction, users moved the head far lesser distance in mixed environment than in game setup in attaining the same goal. In a mixed task, users exhibited far less lateral and transverse movements owing to the video scene that was overcast in the scene. This was thought to have given the user a contextualization of their posture since the video positioning (y-axis position and x-axis rotation) was affected by the head turns and rotations. The effect is clearly visible in Figure 6-11(b) where the users had a symmetrical distribution around zero in mixed and video tasks as compared to game task.

From these, the video texture that followed head rotation and positions was useable to give contextual feedback of users' positioning in 3D space. A similar effect can be obtained using floating objects or avatar.

6.4.4 Limitations

The scene design strategies, gathered from previous research and practice, were employed in the current experiment. Since the target of the present study was not on motion sickness, the effectiveness of the strategies cannot be confirmed as yet. Further investigation and analysis are required. From the completed subjects' verbal assessment, there was none, or reduced discomfort induced by the content apart from one subject (who reported to be highly susceptible to car motion sickness) who could not complete the experiment. Further experimentation is needed to verify the utility of the current setup in comparison with alternatives. As a future endeavor, car-centric design, where the engagement content are displayed in a 2D screen in a car as described in [96] and compare the same with an environment-centric design. The contents in use should similarly be expanded to get a comprehensive view of engagement and the role it plays in hampering motion sickness effects.

The present paper investigated four tasks, game, video, and a combination of these and compared that to baseline, no-task. The activities are not exhaustive with a bias towards entertainment. Further tests and investigations are still needed to fully understand the dynamics of experiences targeting entertainment other activities like office work, reading and writing, amongst others. At present, when users fail to hit a target owing to physical car movement and rotations, the failure was attributed to game-hardship setting, and therefore an acceptable loss. Other serious tasks would require higher accuracy, minimal scene movements, redesign of user interfaces, to name a few.

Besides the highlighted limitations, a sample population featuring students is similarly limiting. Further investigation will be performed to capture a greater audience with different demographics.

CHAPTER VII: CONCLUSION AND RECOMMENDATIONS

7. CONCLUSION AND FUTURE RECOMMENDATIONS

7.1 Conclusion

The research work explored various facets of road safety and methodologies employed to combat the same. In summary, from literature review, the driver was identified as the leading cause of fatality in the roads emanating from differing reasons. This has prompted the transport industry to come up with ways and means of combating the same. Driver assistance and automation has been employed to this end. Particularly, driving automations are being sought at to eliminate current traffic problems. Automation in vehicles is standardized by society of automotive engineering (SAE) with level 0 to 5. The research focused on SAE level 3 and 4, i.e., conditional automation and high automation levels. The main reason is that there is a paradigm shift in road monitoring for the levels where the role of driver changes to a supervisor. Essentially, level 3 and 4 are critical in safety as they as feature a situation whereby the AVs share roads with human drivers. Additionally, drivers in this level will be required to assume control in cases where the autonomous system encounters uncertainties. As such, the road user will be required to be monitoring the road even if they are not actively intervening. Research has shown that automation will lead to more fatigue and loss of vigilance due to inactivity. To ensure safety, the autonomous system will be mandated with driver monitoring and or vigilance enhancement methods before the user can take over control.

In this work, we posit that entertainment will play a major role in maintaining vigilance of the drivers and as such, the ideal activity during transit. For safety, we explore ways of integrating entertainment with road monitoring using 3DAR that meshes road conditions with entertainment. As such, the target is to evaluate driver’s reaction to hazardous conditions during 3DAR entertainment in autonomous vehicles. Behavior change is expected to take effect as driver roles change. Additionally, reliance on automation might be experienced which leads to unpreparedness in the face of an accident. This research proposed a driver monitoring and entertainment schemes to keep the user vigilant and responsive. Use of physiological signal for direct monitoring, i.e., EMG, EDA and pupil size were investigated.

In experiment one, we sought to evaluate response of a driver using indicators like reaction time and physiological signal response (surface electromyogram). The driver was presented with stimulus (collision objects) of different size and distance. From the experiments, use of EMG response to infer muscle toning in preparation of hazardous event was effective where greater muscle activity implied higher preparedness, which translated to greater perceived risk. This suggests that EMG response can be applied in a real driving environment characterize error or hazards.

It is desirable for the driver in an AV to be actively monitoring the road ahead, but this may not be practical. As a remedy, we propose the use of gamification, to engage the driver as well as offer a means of driver monitoring system. The proposed scheme in experiment two and three utilized 3D augmented and virtual reality (AR/VR) games which add value to the automation system as opposed to just entertaining. The experiments considered two distinct environment, parked car (experiment two with seated user) and moving car (experiment three with In-car VR). The tasks evaluated were No-task, video task, game task and a mixture of tasks. For evaluation of recognition of hazards, we utilized staged popup objects and recorded the reaction time of different users.

From the results, no-task had the highest reaction time followed by video task, game task and finally mixed task. One-way ANOVA found significant difference in the means of the groups (F(3,231) = 2.75, p = .0437), with game-task and mixed-task being significantly different from no-task (p = .0126 and p = .016, respectively). Overall, the experiments' difference in reaction time was less than 1 second for all tasks, suggesting that the usage of additional tasks did not negatively affect recognition of popup objects.

From the discussion, driver monitoring through score progression on the road environment by gaming modality has been achieved. Learning, saturation, and decline profile were identified as the main trends that would be useful in contextualizing the engagement model.

When the content is managed by the ADS, it will be possible to make inference of driver state with no adverse effects to recognition of threatening driving scenarios.

As reported from pupil size variation and EDA activity measurements, use of extra tasks was desirable and increased engagement linearly. The methods employed is useable as an indirect measure of engagement, with possibility of manipulating the content, to maintain focus. This would thereby afford a methodology to monitor and maintain vigilance in an autonomous system in the long run. From the results, video and mixed task had the best posture of all the evaluated scenes. This was due to the contextual feedback of users' positioning in 3D space. A similar setup using floating objects or avatar systems is recommended to help the users orient their position in 3D space.

7.2 Recommendation

The activities evaluated herein, which are biased towards entertainment, are not exhaustive. Further tests and experiments are needed to investigate different designs, and the role each play in hampering or otherwise, the effects of motion sickness. In summary, future work is needed in the listed areas and more.

I. Investigation of ideal content deliver (inside-centric delivery of content vs outside-centric model) and the use of diverse activities in an In-car VR

II. Integration of meshed augmented reality display as opposed to occluded head mounted VR. The current setup for VR use was completely occluded and as such the users were unaware of any external location cues.

III. The current experiment lasted between 10-20 minutes in a VR headset. An endurance test is needed to fully identify sustainability in a longer journey. Similarly, motion sickness should be specially looked at as an impediment to the usage of VR in cars.

IV. Further testing is needed to identify what would be the ideal posture in an In-car VR. From a safety standpoint, the use of HMD can adversely affect the effectiveness of airbag due to extra weight and posture.

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APPENDICES

A1. Publication List

A1.1 Research papers that form the basis of thesis

1. Joseph Kamau Muguro, Minoru Sasaki, Kojiro Matsushita & Waweru Njeri. Trend analysis and fatality causes in Kenyan roads: A review of road traffic accident data between 2015 and 2020", Cogent Engineering, 2020,7:1, DOI: https://doi.org/10.1080/23311916.2020.1797981
2. Joseph Kamau Muguro, Minoru Sasaki, Kojiro Matsushita, "Evaluating Hazard Response Behavior of a Driver Using Physiological Signals and Car-Handling Indicators in a Simulated Driving Environment", Journal of Transportation Technologies 9 (04) 439, 2019 DOI: https://doi.org/10.4236/jtts.2019.94027
3. Muguro, J.K.; Laksono, P.W.; Sasatake, Y.; Matsushita, K.; Sasaki, M. User Monitoring in Autonomous Driving System Using Gamified Task: A Case for VR/AR In-Car Gaming. *Multimodal Technol. Interact.* **2021**, *5*, 40. https://doi.org/10.3390/mti5080040

A1.2 Other Publications

A1.2.1 Journal papers

1. M. Sasaki, T., Iida, J., Muguro, N., Waweru, L.,P., Widyo, S.M.b., Amri, R.,M., Ilhamdi "Estimation of the Shoulder Joint Angle Using Brainwaves," Andalas J. Electr. Electron. Eng. Technol. (AJEET), 2021 DOI: https://doi.org/10.25077/ajeeet.v1i1.5
2. Laksono, Pringgo Widyo.; Kitamura, Takahide; Muguro, Joseph; Matsushita, Kojiro; Sasaki, Minoru; Suhaimi, Muhammad Syaiful Amri bin. Minimum Mapping from EMG Signals at Human Elbow and Shoulder Movements into Two DoF Upper-Limb Robot with Machine Learning. *Machines* **2021**, 9, 56. https://doi.org/10.3390/machines9030056
3. Laksono, Pringgo Widyo.; Matsushita, Kojiro.; Suhaimi, Muhammad Syaiful Amri bin.; Kitamura, Takahide; Njeri, Waweru; Muguro, Joseph.; Sasaki, Minoru. Mapping Three Electromyography Signals Generated by Human Elbow and Shoulder Movements to Two Degree of Freedom Upper-Limb Robot Control. *Robotics* **2020**, *9*, 83. https://doi.org/10.3390/robotics9040083
4. Sasaki, M., Yamauchi, S., Hayashi, H., Ito, S. ., Koide, S., Tomabechi, K. ., Mizutan, K., & Muguro, Joseph. Development and Launch of an Experimental Rocket with an in-built solar-powered quasi-satellite with

contra-rotating propeller. JOURNAL OF SUSTAINABLE RESEARCH IN ENGINEERING, 2020, 6(2), 65-77

5. Sasaki, Minoru; Tochigi, Hideaki; Njeri, Waweru; Hayashi, Hiroyuki; Muguro, Joseph; Matsushita, Kojiro; Ngetha, Harrison; "Robust posture tracking control of stable coaxial two-wheeled AGV using the approximate inverse system and LMI" JASTED Vol. 4:1, 2020
6. Minoru Sasaki, Eita Kunii, Tatsuya Uda, Kojiro Matsushita, Joseph K. Muguro, Muhammad Syaiful Amri bin Suhaimi and Waweru Njeri, Construction of an Environmental Map including Road Surface Classification Based on a Coaxial Two-Wheeled Robot, JOURNAL OF SUSTAINABLE RESEARCH IN ENGINEERING Vol. 5 (3) 2020, 159 – 169.

A1.2.2 Conference papers

1. Muguro, Joseph. K.; Sasaki, M.; Matsushita, K.; Njeri, W.; Laksono, P. W.; Muguro, J. K.; Sasaki, M.; Matsushita, K. Development of neck surface electromyography gaming control interface for application in tetraplegic patients ' entertainment development of neck surface electromyography gaming control interface for application in tetraplegic patients' entertainment. In AIP Conference Proceedings 2217,030039(2020); https://doi.org/10.1063/5.0000500
2. Sasaki, M.; Matsushita, K.; Rusyidi, M. I.; Laksono, P. W.; Muguro, J.; Syaiful, M.; Njeri, W.; Sasaki, M.; Matsushita, K.; Rusyidi, M. I.; Laksono, P. W. Robot control systems using bio-potential signals robot control systems using bio-potential signals. In AIP Conference Proceedings 2217, 020008 (2020); https://doi.org/10.1063/5.0000624
3. Laksono, P. W.; Sasaki, M.; Matsushita, K.; Suhaimi, M. S. A. bin; Muguro, J. Preliminary research of surface electromyogram (SEMG) signal analysis for robotic arm control. In AIP Conference Proceedings 2217, 030034 (2020); https://doi.org/10.1063/5.0000542
4. Minoru Sasaki, Eita Kunii, Tatsuya Uda, Kojiro Matsushita, Joseph K. Muguro, Muhammad Syaiful Amri bin Suhaimi and Waweru Njeri, Construction of an Environmental Map including Road Surface Classification Based on a Coaxial Two-Wheeled Robot, In Sustainable Research in Engineering Conference, 2019.