Trends in Electrodermal Activity, Heart Rate and Temperature during Distracted Driving among Young Novice Drivers.

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Driver distraction, defined as the scattering of attention from critical activities for safe driving, is among the key globally recognized contributing factors to road crashes. The trend keeps increasing with in-vehicle information systems and hand-held devices, leading to inattention. Of people in all age groups, young novice teenagers are prone to the risk of road crashes and are also more likely to exhibit risky and unsafe driving behavior. Data shows that the involvement of distracted drivers in fatal & injury collisions is higher for people aged between 16 -34, which is about 55%. Therefore, young drivers are of great concern for the research about driving and evaluation of safe driving conditions, which is vital in upcoming advancements in autonomous vehicles.

Several research studies have explored the effects of distracted driving using face tracking and eye glance monitoring. Previous research [50] did not consider much about the effect of distraction on physiological factors and their impact during driving. The current study used data collected from a previous thesis work titled “Detection of Driver Cognitive Distraction Using Machine Learning Methods” by Apurva Misra and conducted new data analysis focusing on new research questions. The main objective of this thesis is to study, identify and discuss the effects on physiological factors like heart rate (HR), electrodermal activity (EDA), body temperature, and motion sickness during distracted driving among young drivers.

The data was collected from a driving simulator study comprising 42 participants aged 16 – 23 under normal and distracted driving conditions. Their driving experience ranges from 0 to a maximum of 5 years. Each participant navigated six scenarios, three with distraction and the rest without distraction. Each scenario has a hidden, latent hazard depending on the surrounding; for example, in the work zone scenario, a worker is hidden behind the bulldozer in the work zone. The distraction task is a spoken task for which the driver has to respond verbally, which exerts a workload similar to that observed in conversations using a hands-free mobile phone. The physiological data collected through the Empatica4 wristband was analyzed and compared against age, gender, driver experience, and another parameter like motion sickness score (MSS) obtained from a questionnaire the participants completed after the experiment. Of the physiological factors stated above, it was found that HR and EDA play a significant role while studying distraction. Data analysis showed that HR and EDA increase more during distraction than baseline events. Nearly 80% of drivers with 0 or 1 year of experience tend to have a higher range of HR and EDA, which reveals that they are more distracted than their peers with more experience. From the results of the Load index questionnaire and Motion Sickness susceptibility questionnaire, it is inferred that when MSS increases, there is an increase in HR and EDA. These findings will provide insights into physiological factors for developing distraction mitigation systems or in-vehicle warning systems for distracted drivers.

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List of Abbreviations

- ANS – Autonomous Nervous System
- CNC – Crash / Near Crash
- DBQ – Driver Behaviour Questionnaire
- ECG – Electrocardiogram
- EDA – Electrodermal Activity
- EEG – Electroencephalogram
- EMG – Electromyogram
- EOG –Electro Oculogram
- GSR – Galvanic Skin Response
- HCI – Human Computer Interaction
- HMI – Human Machine Interaction
- HR – Heart Rate
- HRV – Heart Rate Variability
- IBI – Inter Beat Intervals
- IVIS – In-Vehicle Information System
- MSQ – Motion Sickness Questionnaire
- MSSQ – Motion Sickness Susceptibility Questionnaire
- NHTSA – National Highway Traffic Safety Administrator
- PNS – Parasympathetic Nervous System
- PPG – Photoplethysmography
- SC – Skin Conductance
- SNS – Sympathetic Nervous system
- SSQ – Simulator Sickness Questionnaire
- TLX – Task Load Index

Chapter 1

Introduction

1.1 Motivation

According to the global status report on road safety by the world health organization, it was estimated that the number of road traffic death was about 1.25 million a year on a global scale [1]. This claims that road crashes have a huge impact on the development of technologies for safer driving.

The US National Highway Traffic Safety Administration (NHTSA) states that eight percent of fatal crashes, and 13 percent of all reported motor vehicle crashes in 2020 were reported as distraction-affected crashes [2]**.** In 2020, there were 3,142 people killed and additionally 324,652 people injured in motor vehicle crashes that involves distracted drivers [2]**.** Seven percent of drivers around 15–20 years old have reported as distracted during fatal crashes. Figure 1.1 shows that this age group has the largest proportion of distracted drivers during fatal crashes, says NHTSA [2]

It is very important for the upcoming advancements in the automobile industry which is leaping towards autonomous cars, to look at the aspects of safe driving. The crash or near-crash mitigation is vital for this to be achieved. From the discussion above, it could be inferred that the impact of distracted driving is of great concern to be considered when it comes to developing technologies for safe driving.

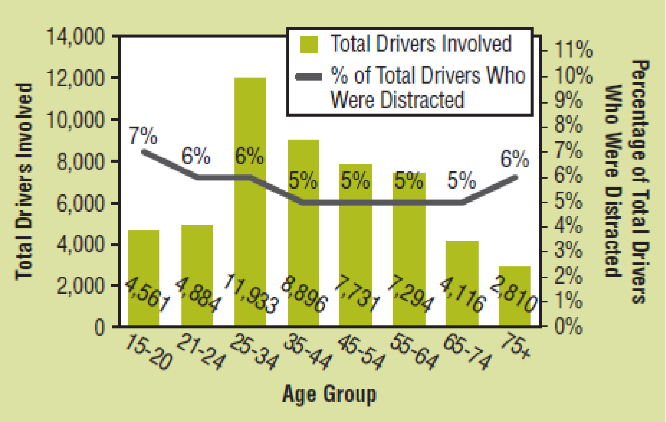


Figure 1.1 Driver involved and percentage of drivers involved in fatal crashes who were distracted, by age group,2020 **[2]**

1.2 Objective and Importance

Distracted driving is a significant safety problem. This distraction is often discussed around hand-held devices like mobile phone usage and texting. But distraction also includes activities like eating, talking to co-passengers, or using in-vehicle information systems (IVIS).

A driver-assisted system like IVIS can also inform drivers about getting distracted and alert them of their surroundings so that they can drive safely without any crashes or accidents. Several research has been done on this “distracted driving,” which uses vehicle kinematics, eye-glance monitoring, face monitoring, etc. However, when it comes to cognitive distraction, Physiological factors play a major role.

When considering the drivers, young drivers are known for an increased tendency towards unsafe, risky driving and have a high risk of crashes too. Many of these have more implications for distracted driving.

This thesis involves studying and understanding of physiological factors, their effect, and their importance while the drivers get distracted, especially among young drivers of age 16 to 23 years old.

1.3 Thesis Organisation:

The content of this thesis is structured as given below:

- Chapter 2 provides a background of this thesis, literature regarding distracted driving, consideration of young drivers and physiological factors in distraction. The gap in the literature is also discussed**.**
- Chapter 3 discusses the data collection methods and material for the experiment, distraction tasks and the participant questionnaires.
- Chapter 4, an exploration into physiological data, synchronizing, and visualizing them are elaborated and discussed. This chapter also discuss about the observation and insights obtained.
- Chapter 5, Conclusion, gives a summary of the study, its limitations and its future work.

Chapter 2

Background

2.1 Literature review

2.1.1 Distracted driving

Driver inattention or distracted driving means insufficient or no attention to activities critical for safe driving and completing the activity, which may lead to unsafe and risky driving [7]**.** Distracted driving or inattentive driving, which is 14% to 17% of crashes, is associated with hand-held devices while driving [6][14]. It happens primarily due to electronic devices like cell phones which is about 24% and other activities like grooming, eating, drinking, etc. [3]**.** In-vehicle technology is also a contributing factor in driver distraction. Nevertheless, they are also an excellent source to get data on the drivers for distraction mitigation.

The hand-held devices used by the drivers increase the reaction time by 0.5 to 1.5 seconds which makes it difficult to maintain speed, response and impairs one's judgment [4][12][13]. Mostly non-commercial vehicles tend to have 2.8 times more crashes on the road than other vehicles [4]**.** Analysis of eye glance behavior done by Road Safety in Canada indicated that the eyes-off the road durations of greater than two seconds significantly increased the risk of crashes [3]**.** 22% of distracted crashes happen when a secondary distraction leads to cognitive distraction [3][14]. Not only hand-held devices, even hands-free phones or the use of user interface in the vehicle also slows the reaction time. Therefore, not much difference is seen between hand-held and hands-free devices. These distracted drivers accounted for 14.8% of all traffic-related fatalities in 2012 [4]**.** Several causes of distraction while driving are shown in Figure 2.1.

Figure 2.1 Causes for distracted driving **[8]**

According to NHTSA’s record for the year 2015, 72,000 police-reported crashes involved drowsy drivers. This drowsiness or tiredness happens due to fatigue. Fatigue occurs when a person works beyond a point, leading to a decrease in efficiency [9]**.** Fatigue is another critical category of distraction after cognitive distraction [**9**][10]. An interesting study shows that the driver's familiarity with the road routes and traffic may also affect the psychological state of the drivers and their driving behavior. The driver becomes more lethargic about the environment and pays much less attention which also comes under distracted driving [11].

2.1.2 Young drivers

Teen and novice drivers are known for the increased risk of road crashes. Driver distraction is focused on teenagers because of their inexperience and their proneness to engage in risky and unsafe driving [15].

According to Road Safety in Canada, drivers aged 16-24 are 13% only, while their fatalities and getting seriously injured were about 24% and 26%, respectively [3]. Of all other age groups, young drivers 16 to 24 years of age continued to have a higher risk of being killed in a motor vehicle crash, as seen in Figure 2.2.

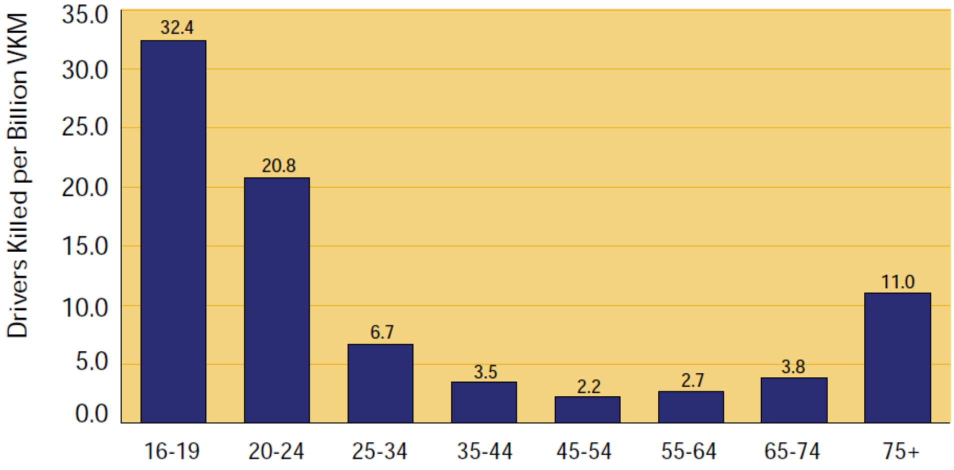


Figure 2.2 Young drivers are overrepresented as victims **[3]**

Data for the involvement of distracted drivers in fatal and injury collisions are higher for ages 16 -34, which is about 55% [3]**.** Therefore, secondary tasks make them more susceptible to being cognitively distracted. Several reasons for considering teen drivers have more implications in the area of distracted driving. They include widespread usage of mobiles while driving, In-Vehicle Information Systems (IVIS) and distractions inside and outside the vehicle, making them more susceptible to distraction.

In-vehicle distractions may include the presence of co-passengers which are known as a risk factor for crashes while interacting with a teen driver. The co-passengers are also observed to influence the drivers' behavior and decision-making [15]. Three naturalistic studies conducted on teen drivers, to show the prevalence of distracted behavior. But they were conducted only in states of the US where there are laws limiting the usage of cell phones for teen drivers [28]. These studies reveal that the estimate of electronic device usage may not reflect the electronic device used during all driving conditions [28].

Several studies that were done by comparing teen's and adult's phone usage while driving show that drivers of age 18 -20 years old are more alike to 21 -24 years old than drivers above 25 years [22][23][24][37]**.** A naturalistic study on teen drivers shows that the eye glance away from the roadway mostly involves secondary tasks. The glances which are more than two seconds were associated with four times increase in Crash/Near Crash (CNC) for any secondary task considered [35]and is about 56.7% of study scenarios [16].

A field study from England also shows that inexperienced drivers have longer eyeglance than experienced ones [19][26][27][30 – 33][38]. Other studies also show that newly licensed teens were found to have high crashes when compared to other drivers with good experience [20][24][31][34]. The presence of peer passengers also had a significant influence on distracted driving in young drivers [17][18][21][25]. An examination of such conditions confirms that an increase in younger co-passengers tends to increase the risk of driving among drivers aged 16 -17 years [36].

These studies on young drivers give us more reasons why they are of great interest when considering distracted driving.

2.1.3 Factors and ways of detecting distraction.

The increasing prevalence of autonomy in automobiles makes us depend more on the sensors. The Literature review from [7] concludes that using physiological parameters can be best to monitor the cognitive distraction of the driver.

Research on SHRP2 data from a Naturalistic driving study conducted by Louisiana Transportation Research Centre gives us an overall analysis on SHRP2 data to quantify the crash risk associated with distracted driving behavior [5]. They tried different algorithms to find the best input for analyzing distracted driving. The input data were driving performance, face- eye tracking and physiological measures. Driving performance was considered to determine how distraction and workload levels affect the driver’s control on the vehicle. Face-eye tracking were considered to determine the time when the driver is not engaged in the critical task for safe driving. Physiological measures were taken into consideration to improve the performance of distraction detection methods. The research shows that a combination of a few factors from driving performance measures and face-eye tracking are good inputs for a model [5]. Similarly, there are so many studies that use various algorithms like SVM, RF, KNN etc., [7][8] to identify the distraction among the drivers and also to evaluate which of them performs better **[45]**[45]- [51][74]. Many machine learning algorithms also uses image - or video-based approaches to detect distraction in drivers [75]**.**

A paper regarding the classification of driver distraction uses similar inputs like head posture, vehicle inputs, eye gaze and physiological indicators as input to determine the best–performing algorithm for detecting driver distraction [6]**.** Three classes of distraction, non-distraction, cognitive distraction and texting, are considered. The data was collected through a simulator task. The drive consisted of eight phases with two minutes break to respond to the questionnaire. The loaded drives consist of secondary tasks, which includes:

1. Verbal response for math or analytical question
2. Emotional (questions)
3. Sensorimotor which includes texting.

The dataset consisted of driver behavior measures for each drive. The driver behavior data and physiological data were collected at 60Hz and are down-sampled to 1Hz in the dataset. Twenty-one algorithms were tested, and six showed that the combination of driver and physiological data gives more accuracy [6].

While discussing the physiological factors considered in the study of distracted driving factors like eye gaze, eye movement, electrocardiogram (ECG), Electromyogram (EMG), electrodermal Activity (EDA) and heart rate (HR) are commonly taken into consideration [38][56]. A Study [7] states that physiological factors like the value of pupil diameter can also be used for the detection of cognitive distraction [53].

A pupil dilation study of Safety Vehicle using adaptive Interface Technology (SAVE-IT) shows that increased cognitive distraction leads to increased pupil diameter [56]. Further works on this highlighted the difficulty in estimating cognitive distraction using pupil diameter during a dialog task [54], different lighting conditions [55] and in different emotional states [56]. A study on visual distraction, which includes eye movement for detecting distraction, states that eye tracking has practical limitations for implementing in a distraction detection system because the tracks may lose accuracy when traveling on rough roads [47][14].

A study [49] about detecting physiological patterns in Human-Computer Interaction (HCI) discusses physiological signal based HCIs that have found applications in nonmedical fields like emotion recognition [59]**,** smart home control [60]**,** driver distraction avoidance [61], musical expression [62] and medical fields like healthcare monitoring systems [63][64][65][66]**.** A smartwatch or Fitbit is a practical application of health monitoring, which uses physiological signals [67].

A study on driver's fatigue says that fatigue will also lead to inattention which may lead to distracted driving. This study uses physiological measures like HR, ECG, electrooculogram (EOG), Electroencephalogram (EEG) and Galvanic Skin Response (GSR) [9][10]**.** Another real-world driving study for detecting stress using physiological sensors like ECG, EMG, EDA and HR reveals that these factors correlates with the driver's stress [57]**.** The study states that the Skin Conductance (SC) and the HR are two main factor that can influence stress. This can be taken into consideration because when drivers get distracted, they tend to get stressed which in turn affects the physiological factors [57][58]**.** Other factors like EMG and EEG cannot be used as they are intrusive and incompatible in an actual driving environment.

The literature study of the physiological measures used in distracted driving studies shows that HR is more sensitive to various loaded tasks, particularly for cognitive efforts [56][39]-[42]. Another paper on the effect of electronic devices takes cardiovascular activity as an essential physiological factor for determining the effect of electronic devices while driving [13]**.** The heart rate is ventricle contraction, also known as pulse per time. Doing activities, age, body position, emotional state and fatigue are some of the factors that can impact the heart rate [67]. A Research that was done on Heart Rate Variability (HRV) and its impact on emotions show an intricate involvement of HR with our emotions. It reflects on the physiological state and level of emotional arousal [68]**.**

Electrodermal activity (EDA), also known as Galvanic Skin Response (GSR), is an electrical change that occurs in the skin. The measurement of these are usually from the palm or the sole. EDA is sensitive to any behavior that affects the sympathetic nervous system [56]**.**

A study conducted by decomposition on raw GSR gives the most discriminative characteristic to identify driver distraction. This study also states that the GSR is a reliable indicator and also an early indicator of the distraction state of the driver [69][73][43][44]. The research on GSR and its correlation with emotions shows an apparent increase in GSR activity when a person experiences an emotion. However, there are some exceptions like relief or feeling contented, where there will be a decrease in GSR [70][71][72]. The study [76] proposed GSR-based distracted driving identification. It is said to be a low-cost and robust physiological signal to measure, which is also a minimally intrusive modality that can be measured on the wrist [77]-[81].

Another study on prediction of driver distraction also reveals GSR as an excellent physiological indicator of cognitive state and emotional state. By studying and measuring EDA, one can reveal the change in the Sympathetic nervous system (SNS), which drives all other human behavior at the subconscious level [80]**.** Studies about cognition, stress and cognition also shows that EDA and heart rate has a significant relationship with them [70] [102][103].

The nervous system plays a vital role in a person's reactivity, especially in behavior and physiological factors. The Autonomous Nervous System (ANS) plays a role in all involuntary activities like the increase and decrease of HR and EDA during a distracted condition which may lead to stress. This ANS comprises the Sympathetic Nervous System (SNS) and Parasympathetic Nervous System (PNS). SNS increases the physiological arousal when activated, while PNS acts in contrast, inhibiting the physiological arousal when activated [68]. This understanding of the nervous systems help us know how HR and EDA vary when drivers are getting distracted [70][71][72]. The overall Nervous system is depicted in Figure 2.3 [68].

Several studies conducted using simulators usually includes Motion Sickness as an important factor. The studies reveal that there is correlation between the Motion sickness and physiological factors [82][83][86]. The studies [82][83] states HR, followed by GSR as important physiological factor that correlates with motion sickness and simulator sickness. The study of motion sickness uses the Motion Sickness Questionnaire (MSQ), which records individual exposure to motions in different transportation systems like cars, buses, trains, ships, airplanes, etc., and their corresponding level of occurrence of illness in these transportations [82]. The susceptibility of motion sickness is usually collected through such questionnaires. These responses are used for several motion and motion sickness-related studies. Similarly, for the studies in a simulator environment, the Simulator Sickness Questionnaire (SSQ) can be used to determine whether the participant has simulator sickness or not [83]. The studies above also state HR as a Physiological critical factor that co-relates with motion sickness and simulator sickness.

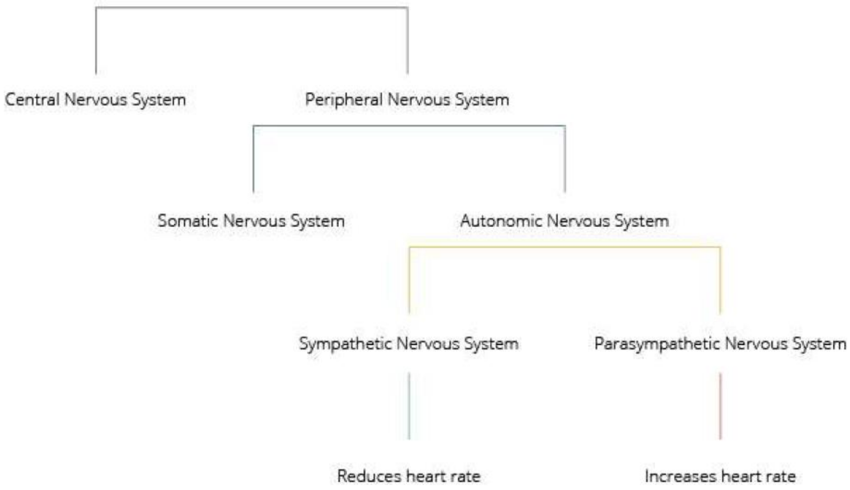


Figure 2.3 Overall nervous system in human body [68]

2.2 Gap in Literature

From the literature discussed above, most of the distraction task was solving a math problem or analytical or logical questions, which are not the actual distraction that happens while driving in a real-world driving situation on roads [84][85]. In order to fill this gap, this simulator study [50] makes it much similar to a conversation among the co-passengers in the vehicle.

There are several researches done on distracted driving, as discussed in the literature study. For detecting distraction, most studies considered vehicle parameters like acceleration, braking force, etc. They also considered pupil and eye tracking as essential data to analyze the distraction. Studies were done combining them and physiological factors as hybrid measuring inputs for their machining learning algorithm.

However, there has not been much research done on the physiological factors and their impact. Even if they are considered, it was to detect the distraction and evaluate the algorithms' performance. This thesis explores the physiological factors specifically. HR, EDA, and body temperature are the physiological measures obtained from the study [50]**.**

As discussed in section 2.1.2, young drivers are most susceptible to distraction than any other age group. Therefore, this thesis considered the simulator study, which mainly focused on the age group of 16 -23 years old. Another essential thing considered in this study is the Behavioral Questionnaire, Motion Sickness Susceptibility Questionnaire (MSSQ) and Load Index Questionnaire (NASA-TLX) obtained from the participants for the driving tasks with and without distractions.

The next chapter discusses the data collection method, materials and equipments for the study, explanation of the driving task and questionnaire obtained from the participants.

Chapter 3

Data collection and Experiment

3.1 Method and material

3.1.1 Hypothesis and study overview

This study was aimed towards young drivers. The physiological factors like EDA , HR and Temperature for Baseline and Distracted driving are obtained during their drive. The Experience of the participants and their Motion Sickness score (MSS) are considered while evaluating the EDA and HR to know the correlation between them.

When considering the baseline and distracted values of EDA, HR and Temperature,

Null hypothesis, ***H_0:*** there is no change in EDA, HR and Temperature values between Baseline and distracted and

Alternative Hypothesis, ***H_A:*** there is change in EDA, HR and temperature values between Baseline and Distracted

When the driving experience of the participants obtained through the questionnaire is considered, the null and alternative hypothesis is stated as :

H_0: There is no correlation between experience and EDA, HR and temperature of the participants and

H_A*:* There is correlation between of experience and EDA,HR and temperature.

When MSS is considered , the hypothesis is that

H_0: There is no correlation of MSS between EDA, HR and Temperature and

H_A*:* There is correlation of MSS between EDA, HR and Temperature.

When considering the workload with and without distraction,

H_0: The Workload score do not increase with distraction.

H_A: The workload Score increases with distraction.

The values of the physiological factors are obtained through sensors in wrist band worn by the participants. The MSS, Workload score and experience are obtained through questionnaires.

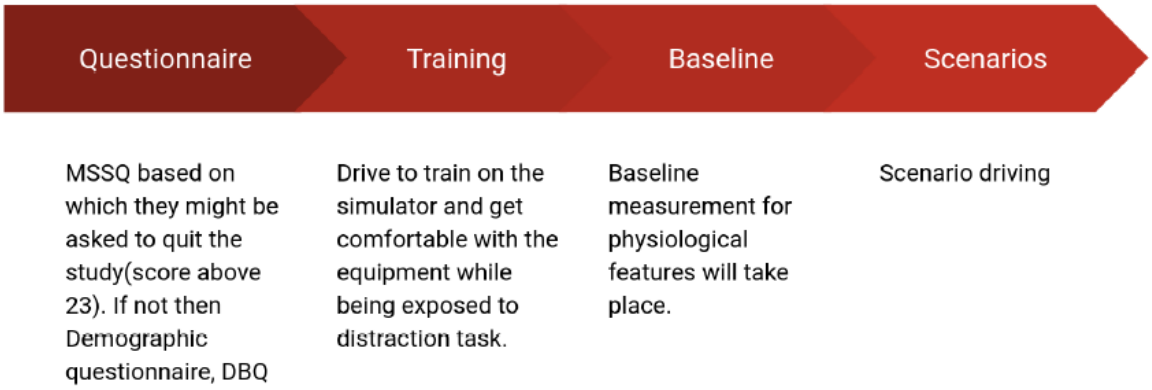
3.1.2 Participants and procedure.

The current study used data collected from a previous thesis work titled “Detection of Driver Cognitive Distraction Using Machine Learning Methods” by Apurva Misra and conducted new data analysis focusing on new research questions. The previous study gives the procedure for the simulator study [50]. At the University of Waterloo, 42 participants were recruited for this study from emails submitted to several departments. Participants were with a full G Canadian driver's license in good standing, less than 15,000 kilometers of driving experience and aged between 18- 23. Participants were required to have adequate eyesight or to have their vision corrected with contacts or spectacles. Participants with known vertigo or motion sickness were not permitted to participate because they were susceptible to simulator sickness [50]**.** There were 42 participants, with a mean age of 20.5 (female=20.78 and male=20.34). There were 14 female and 28 male participant. The study was granted ethics clearance (ORE # 40678) through the University of Waterloo Office of Research Ethics and was conducted as stated in the approved protocols.

Procedure: The participant must sign the consent form if they decide to take part. They were asked to complete the Motion Sickness Susceptibility Questionnaire (MSSQ), which is attached as Appendix A. Depending on the results, they may be asked to stop the study in order to avoid simulator-induced sickness. The participant was asked to fill out demographic information and a DBQ (Driver Behaviour Questionnaire) that rates their driving on a scale of

0 (good driver) to 5 (bad driver) once they have qualified (score less than 23) from MSSQ scoring [50].

The average length of the study was 50 minutes. The study involves a driving simulator for driving task and a wristband with sensors to collect physiological data during driving. Before starting the study, participants have to drive a car through a training scenario in the simulator, consisting of a suburban road with no traffic and multiple turns. This helps to establish competence in handling the equipment. The baseline data from the physiological sensor was collected while this is done. The experimental flow of the study is represented in the Figure 3.1below.



MSSQ based on which they might be asked to quit the study(score above 23). If not then Demographic questionnaire, DBQ

Drive to train on the simulator and get comfortable with the equipment while being exposed to distraction task.

Baseline measurement for physiological features will take place.

Scenario driving

Figure 3.1 Experimental flow of study **[50]**

The following sections go into further detail on the six road scenarios that participants drove through, each of which has a different atmosphere and speed limit. These situations are roughly equal in length, and throughout them, speed and other driving and physiological factors are noted [50].

3.1.3 Experimental setup

The experiment uses Carnetsoft Driving Simulator for virtual driving tasks consisting of distractions from a navigation window and heeds the traffic regulations. The sound from the road, wind, engine noise and audio for distraction tasks are through speakers. The physiological factors needed for this study are obtained using E4 Empatica Wrist Band. All these equipments are kept in a closed room without windows. The experimenter was the only person present in the room at all times while the experiment was taking place, and the lights were left on throughout [50]. Depending on their level of equipment comfort, the participants were informed that they could ask to quit the experiment at any time. The equipments are explained as follows.

1. Carnetsoft Driving Simulator: This simulator is considered the most realistic car driving simulator. The crucial elements needed for driver instruction are worked on by this driving simulator. It forces the user to repeatedly do actions like changing gears, changing lanes, and watching traffic, among others. Driving is not at all a simple job; several various tasks must be mastered, carried out, and combined, which include indicators must be turned, lanes must be changed, gears must be changed, traffic laws must be followed, traffic signs must be observed, the car must be stopped, the pedals must be controlled, the side and rear-view mirrors must be observed, and many more tasks.

   The simulator contains three screens—left, center and right—with 210 degrees of surround visuals with a resolution of 5760 x 1080, as seen in Figure 3.2. Its lighting, shadows, and motions are all realistic. To evaluate hazard anticipation, animations of people, animals, and unexpected circumstances can be controlled. In scenarios, the density of traffic participants can be adjusted.

Figure 3.2 Carnetsoft driving simulator setup **[50]**

2. Speakers: These produce sounds similar to those from real world driving situations like the sound from the road, the wind, the tires, the engine, and the distraction task, which involved playing audio at random intervals and adjusting the volume depending on the driver's position inside the scenario.
3. E4 Empatica Wrist Band: Wireless and portable devices that collect physiological data are being used in most of the research. The Empatica E4 wristband is an example of a portable device that can monitor cardiac inter beat intervals (IBIs), heart rate variability (HRV), and electrodermal activity (EDA). It monitors several other acceleration and temperature parameters of the person as well. A research setting that involves interactive dyadic states also utilises E4 Empatica band, Figure 3.4, to get physiological data [86]**.**

Figure 3.3 E4 Empatica Wristband [87]

High-quality data collection sensors are built into the E4 Wristband.

- A PPG sensor measuring blood volume pulse and from which heart rate can be derived.
- An EDA sensor measuring the electrical properties of the skin.
- A 3-axis accelerometer, capturing motion-based activity.
- An infrared thermopile, reading skin temperature.

The E4 is worn like a wristwatch. All of the sensors are embedded in the device: the PPG sensor and the temperature sensor are on the bottom side of the device while the wristband holds the EDA electrodes. The overview of the features of E4 Empatica Wristband is show in the Figure 3.4. Recorded data can then be imported via USB where the user can view and manage the collected data. It is also possible to download raw data in CSV format for processing and analysis.

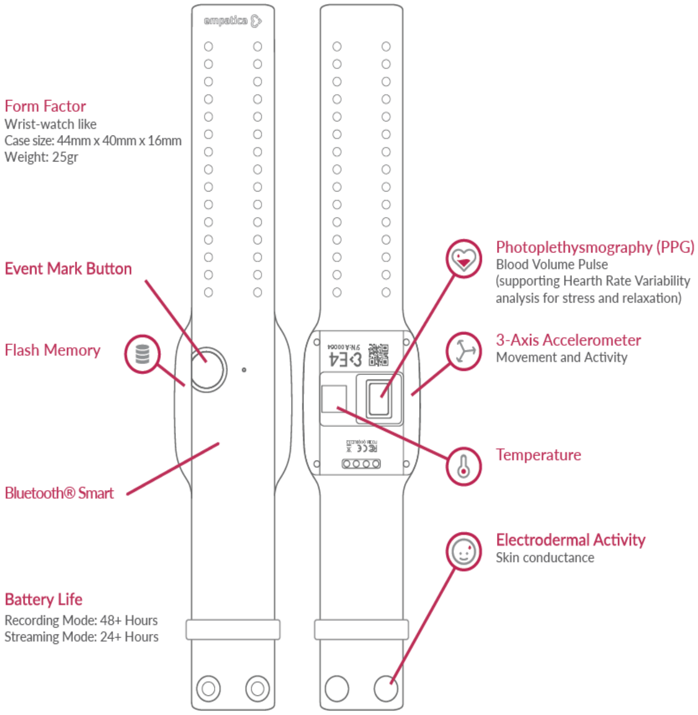


Figure 3.4 Features and placement of sensor in E4 wrist band **[**87]

3.1.4 Distraction Task

The previous study [50] states that, for the driving task, a scenario design was created based on research on drivers' scanning and mitigation patterns for latent dangers. Latent hazards are dangerous threats that could theoretically result in an accident but will not be in these simulator-based situations. In order to examine various driving styles, scenarios spanned a range of road types, from suburban to motorway. They were installed during the day to prevent the impacts of ambient illumination. Each situation had a speed limit communicated through the simulation's signs and announcements before each drive. Each scenario has a latent hazard, and the zone in the thesis centered on that location is referred to as the crucial zone. Latent dangers vary depending on the type of road and its environment. Each participant drove all six scenarios and three scenarios with distractions were chosen in Pseudo-random order.

Therefore, 21 drivers performed a scenario with distraction and 21 drivers performed a scenario without distraction. No driver experienced a scenario twice [50]**.**

The description of the scenario and the latent hazard of each are described as follows:

1. *Work zone scenario:*

   *Speed :*110 km/h

   Environment: work zone in the emergency lane of a two-lane highway, two lanes in each direction with light traffic in opposite lane separated by divider.

   Latent hazard: a worker hidden in the work zone behind a bulldozer, Figure 3.5.a) [50][88][89].
2. *Curve scenario*:

   Speed: 80 km/h

   Environment: Two trucks are parked on either side of a curved segment in a sub-urban road type.

   latent hazard: A pedestrian hidden behind the truck on the right. There is no other traffic participants in this scenario, Figure 3.5b) [50][90]
3. *Stop-controlled intersection scenario:*

   Speed: 50 km/h

   Environment: Stop-controlled four-way intersection in an urban environment

   Latent hazard: stop signage obscured by vegetation. There are no other traffic participants in the scenario, Figure 3.5.c) [50][88][89].
4. *Pedestrian crossing:*

   Speed: 50 km/h

   Environment: A crosswalk at an intersection of a two-lane city road with one lane in each direction. A truck is parked on the left lane.

   latent hazard: A driver hidden behind the truck. There are no other traffic participants in the scenario, Figure 3.5.d) [50][91].
5. *School zone*:

   Speed: 50 km/h

Environment: A sub-urban two-lane road with one in each direction having a crossing in a school zone with early signage cautioning about school children.

Latent Hazard: There is vegetation blocking a pedestrian trying to cross at the crosswalk with the presence of multiple people playing in the park on the other side of the road, Figure 3.5.e) [50][91]

6. *Parked vehicles:*

   Speed: 50 km/h

   Environment: A two-lane road with one in each direction, and the driver has to move straight through along a line of parked cars to the right.

   Latent hazard: a car with its turn signal on trying to pull out into the path of the driver. There are no other traffic participants, Figure 3.5.f) [50][91].

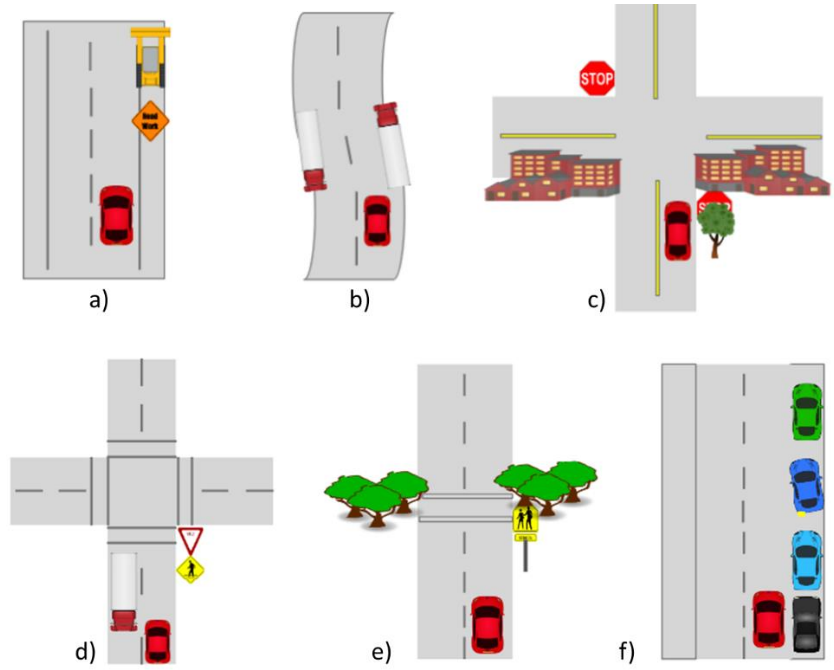


Figure 3.5 The scenarios and the latent hazards for each. a) Work zone scenario, b) Curved scenario with trucks parked, c) Stop controlled intersection with limited visibility, d) Pedestrian crossing with a parked truck, e) School zone scenario, f) Parking zone scenario [50]

Cognitive distraction is a state of reduced or diminished attention. The cognitive distraction of the drivers, which happens due to secondary tasks like talking, and listening to music can be reproduced on a driving simulator by giving tasks like responding to questions that are logical or math problems in general, which act as a cognitive load while driving in the simulator [45]. The cognitive distraction task for this study was a spoken task, but instead of interacting with the experimenter, a series of statements sounded through the speakers at a constant period of five seconds, to which the driver responded. It is initiated in the path preceding the critical zone and terminated in the following path after the critical zone. This secondary task acted as an alternative to conversations carried out while driving vehicles [50].

Before the start of the secondary task, there was a beep to alert the driver and a beep after all the sentences were completed and answered. The sentences were grammatical reasoning tasks that are considered to provide a comparative workload as a hands-free cellphone call.

The sentences in the study [50] were about four to five words long, and after hearing the sentence the participant was supposed to answer in the five-second period before the start of the next sentence.

For example,

Statement: The rat drove the car

Expected response: Rat, Car, No

After each sentence, the participant was required to list out aloud the “subject", “object", “yes/no" - depending on whether the sentence was plausible. An example of positive response from the participant would be-

Statement*: Ron fixed the door*

Expected response: Ron, Door, Yes

3.2 Questionnaires and load index

A study identified that traffic accidents are closely related to the driver's mental and physical state before the accidents, which is obtained through the questionnaire and survey [6]

For this study, each participant were asked to fill out three questionnaires before starting the experiment. The first was a pre-study questionnaire to get the demographic and driving history of the participants [Appendix A].

The second questionnaire was Driver Behaviour Questionnaire (DBQ). There were about 24 statements based on driving behavior, and the participants were expected to fill them on a scale of 0 to 5 (from rarely engaging to engaging almost all the time) based on their own experience [Appendix A].

The last one is the Motion Sickness Questionnaire (MSSQ). This questionnaire is designed to find how susceptible to motion sickness the participants are. The sickness here refers to vomiting, nausea or other similar feelings related to motion. The participants were asked to fill two tables. The tables contain nine modes of transport or entertainment and row against each to mark how frequently they feel sick or nauseated while in that transport or entertainment. The first table was for their experience as a child (before the age of 12) and the next table was for their experience in the last ten years [Appendix A].

Another important information regarding their workload is obtained through NASA Task Load Index (TLX) after the experiment. NASA TLX is a multi-dimensional rating technique for the subjective workload. This describes workload as the effort to achieve a level of performance by humans [92]. The subjective workload integrates weighted subjective responses, including emotional, cognitive and physical responses and their weighted behavior evaluation.

There are six dimensions of subjective experience of workload. They are mental demand, physical demand, temporal demand, perceived performance, effort and frustration level as shown in Figure 3.6. Definition of these rating – scale is presented in Table 3.1.

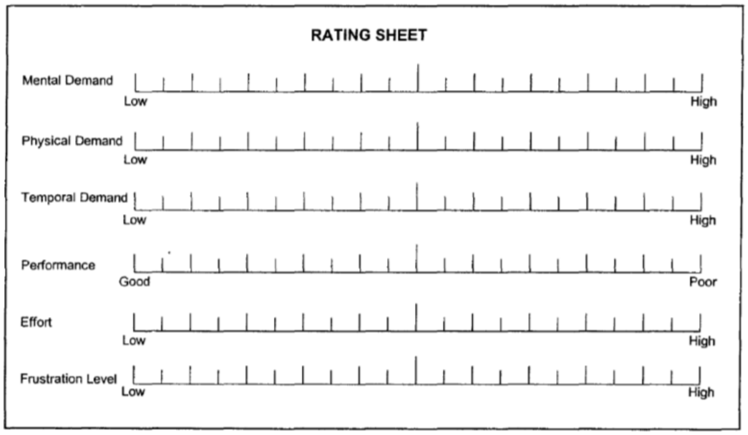
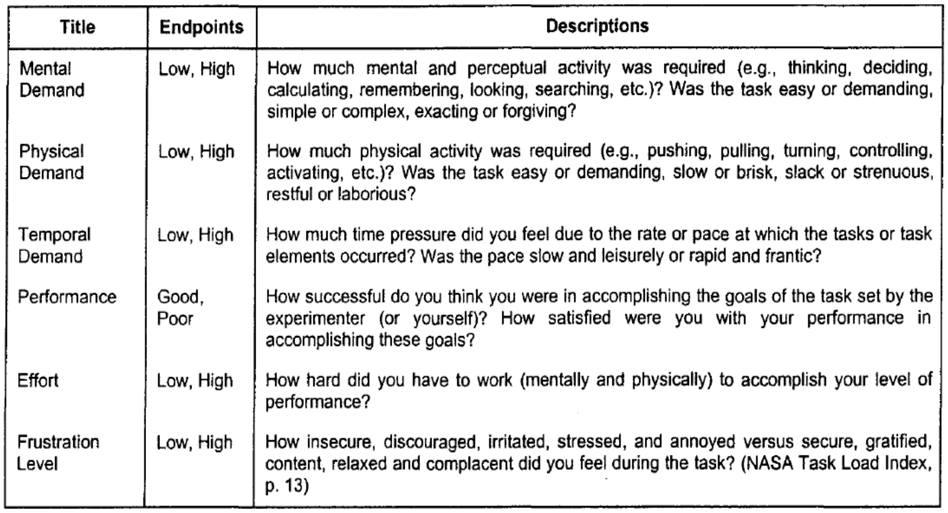


Figure 3.6 Rating scale of NASA TLX [92]



Title	Endpoints	Descriptions
Mental Demand	Low, High	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	Low, High	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low, High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Good, Poor	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	Low, High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration Level	Low, High	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task? (NASA Task Load Index, p. 13)

Table 3.1 NASA TLX rating scale – definitions **[92]**

Many studies that used TLX conclude that it provides a sensitive indicator of workload which is significant, valid and reliable [93] – [97]. They all reported that these rating was obtained within a minute but are extremely useful for estimating workload in an operational environment [92]**.**

Chapter 4
Exploration

4.1 Physiological data

Bio-signal processing is vital for many technologies that use Human Machine Interaction (HMI). These signals can be obtained from the sensors that are used to collect and measure physiological factors like Heart Rate, Electrodermal activity and temperature, which are considered for our study as well.

The measurements for this study were collected from the E4 wristband worn by the participants during training as well as during their drive through scenarios in the simulator. The data collected during training corresponds to baseline measurement and that collected during driving scenario is considered to be distracted measurement [50]. The measurement duration can be controlled using a button on the wristband. The measurement for this study was started when training started and was stopped once the training was done and started again when the participant started experimental scenarios.

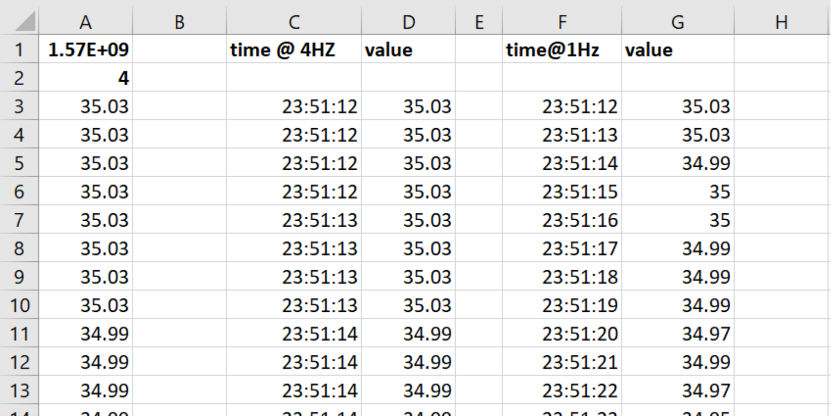
The data obtained from the physiological sensors can be transferred to in real-time to a system. This was further converted in separate folders for each participants in CSV format for HR, EDA and temperature [50].

The following steps were done for data-cleaning:

1. Generating time stamps: the initial timestamp is indicated in cell A1 of the CSV file of each sensor, as shown in Figure 4.1Therefore, the timestamp is generated from this initial timestamp.
2. Synchronization: The collected frequency from the E4 band is represented in cell A2 of the csv file for each senor (Figure 4.1). The frequency of EDA and Temperature are 4 HZ while for HR is it was 1HZ. Therefore,

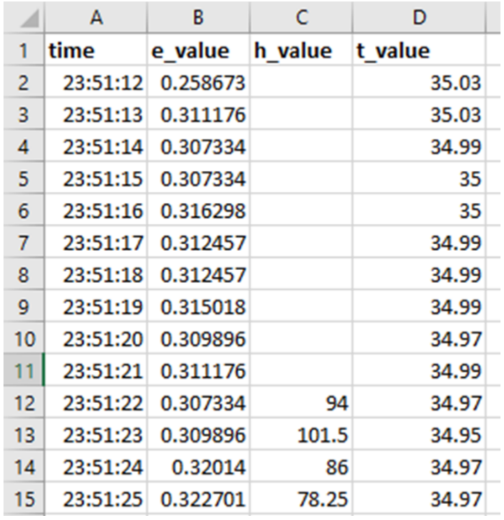
synchronisation is done in order to bring all physiological factor down to 1Hz as shown in Figure 4.2

The processed data for each participant is then compiled into a single folder for each physiological data, including baseline and distracted values. This data is further used for analysis where the baseline and distracted values of EDA, HR and Temperature were compared against each other.



	A	B	C	D	E	F	G	H
1	**1.57E+09**		**time @ 4HZ**	**value**		**time@1Hz**	**value**	
2	**4**							
3	35.03		23:51:12	35.03		23:51:12	35.03	
4	35.03		23:51:12	35.03		23:51:13	35.03	
5	35.03		23:51:12	35.03		23:51:14	34.99	
6	35.03		23:51:12	35.03		23:51:15	35	
7	35.03		23:51:13	35.03		23:51:16	35	
8	35.03		23:51:13	35.03		23:51:17	34.99	
9	35.03		23:51:13	35.03		23:51:18	34.99	
10	35.03		23:51:13	35.03		23:51:19	34.99	
11	34.99		23:51:14	34.99		23:51:20	34.97	
12	34.99		23:51:14	34.99		23:51:21	34.99	
13	34.99		23:51:14	34.99		23:51:22	34.97	

Figure 4.1 Temperature Data with generated timestamps and stepped-down frequency



	A	B	C	D
1	time	e_value	h_value	t_value
2	23:51:12	0.258673		35.03
3	23:51:13	0.311176		35.03
4	23:51:14	0.307334		34.99
5	23:51:15	0.307334		35
6	23:51:16	0.316298		35
7	23:51:17	0.312457		34.99
8	23:51:18	0.312457		34.99
9	23:51:19	0.315018		34.99
10	23:51:20	0.309896		34.97
11	23:51:21	0.311176		34.99
12	23:51:22	0.307334	94	34.97
13	23:51:23	0.309896	101.5	34.95
14	23:51:24	0.32014	86	34.97
15	23:51:25	0.322701	78.25	34.97

Figure 4.2 Synchronized data of EDA, HR and Temperature

The age, experience & gender of the participants are obtained through demographic information filled by the participants. The MSSQ score is also taken into consideration while analysing the physiological features. The explanatory analysis of these features was done and discussed as follows.

4.2 Exploration and observations

The exploratory analysis was done to gather insights about the characteristics of the physiological data. This helps to know the correlation between each feature and sights about their relationship.

The demographic information about the participants, which include their age, gender, experience and whether they wear lens were tabulated together. The MSSQ score was calculated from the questionnaire obtained from the participants. This was also included with demographic information.

Firstly, a basic graph analysis of EDA, HR and Temperature against time is done for a participant. There was little impact on one feature on another. There were fluctuations and peaks seen in EDA and HR lines. However, the temperature does not seem to vary much compared to the other two factors. It was repeated for other participants and it proved the same. An example is given in Figure 4.3, where EDA, HR and temperature of a male and female participant of same age is plotted. The observations are taken into consideration and further exploration of data is done for EDA and HR values.

The EDA values of female and male participants are analysed separately for baseline and distracted events and is represented in the graphs in the Figure 4.4 and Figure 4.5. The observations from these graphs are analysed from various aspects like age, experience, motion sickness score and gender. The ranking of the participants according to the maximum value of EDA is shown as “name- distracted, baseline” in the Table 4.1 and Table 4.2.

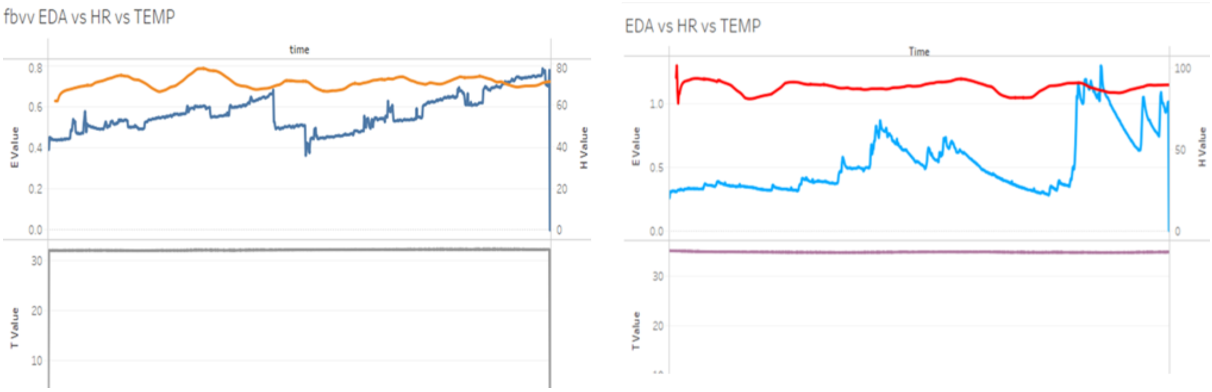
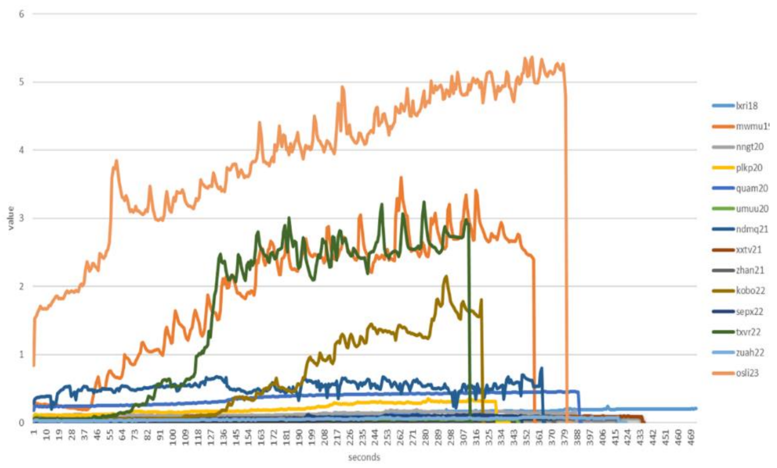


Figure 4.3 EDA, HR and Temperature of a female and male participant of age 22**.**


a) baseline- female

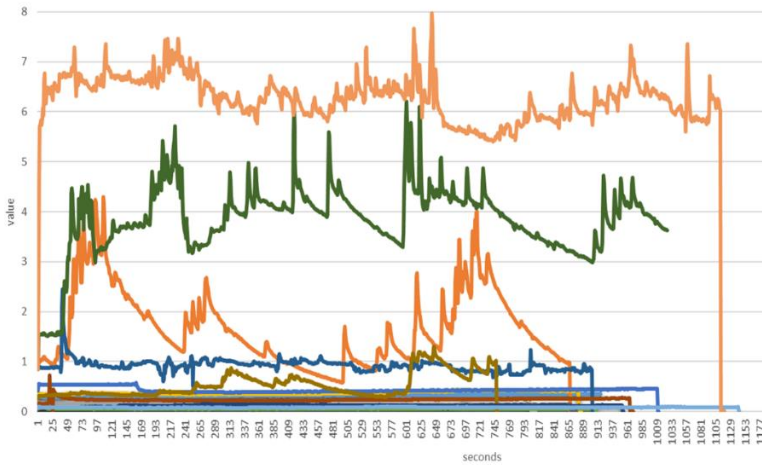

b) dis-female

Figure 4.4 a) Baseline EDA values of Female **b)** Distracted EDA values of female

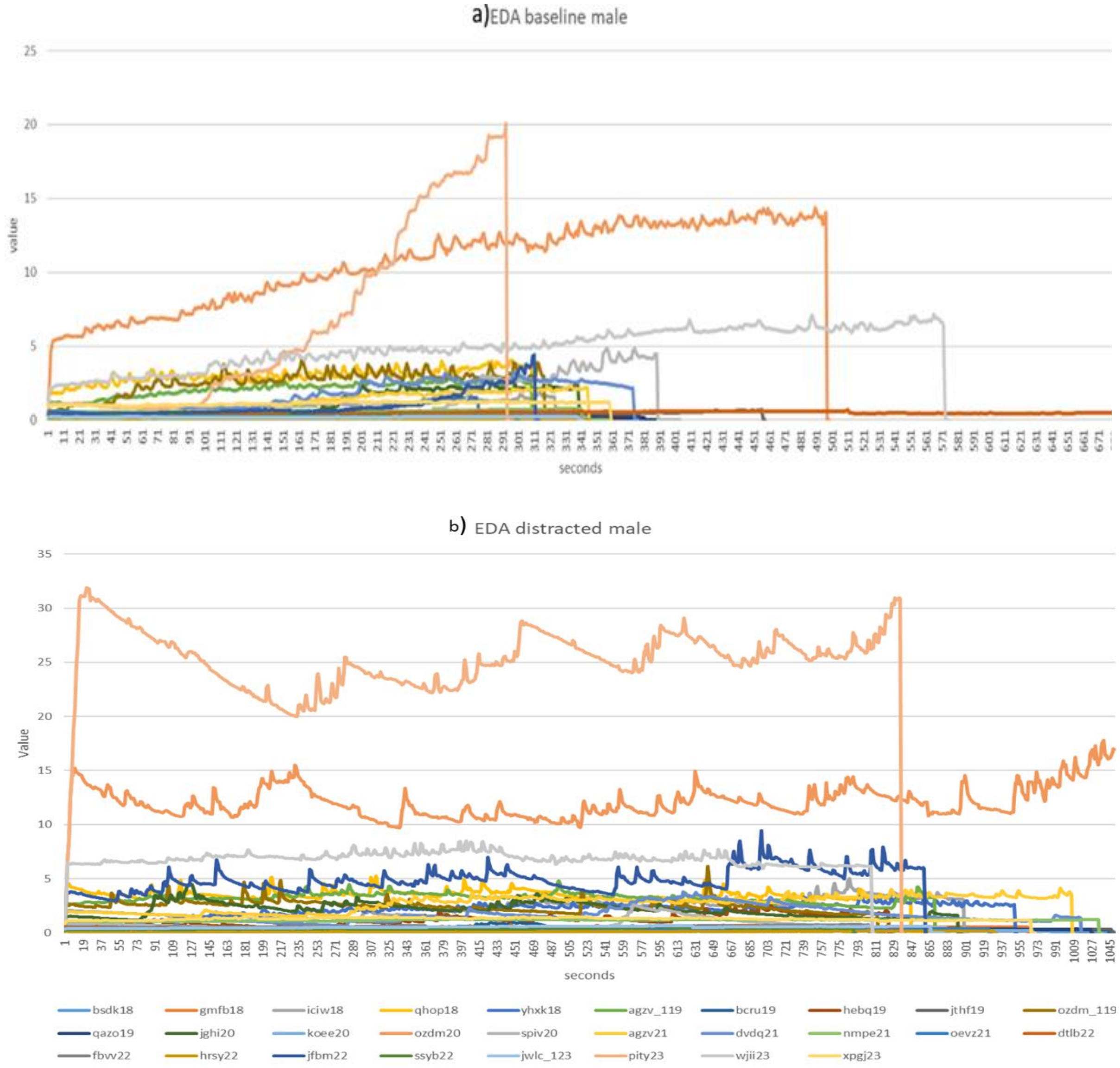


Figure 4.5 a) Baseline EDA values of male **b)** Distracted EDA values of male

There is an overall increase in EDA during distracted events when compared with baseline which could be seen from the example in Figure 4.6 Baseline vs distracted EDA . The peak values are higher in distracted event. It is seen from Table 4.1 and Table 4.2 that the age and gender of the participant do not affect the EDA values. But the experience and motion sickness score seems to have a relationship with the value of EDA.

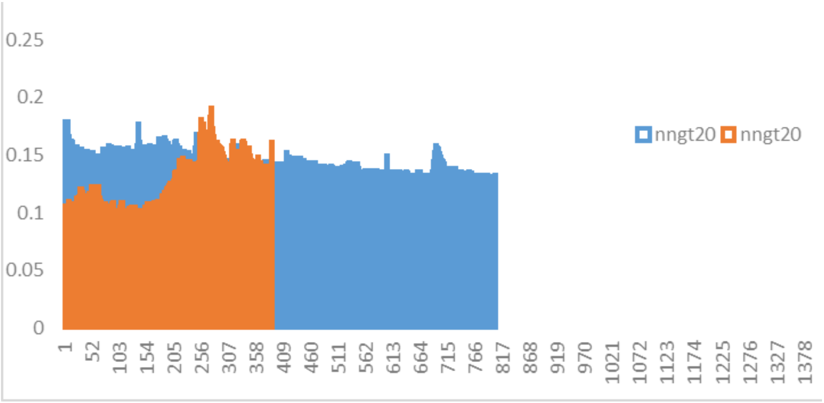


Figure 4.6 Baseline vs distracted EDA

name	age	experience	Motion sickness score	Max EDA	Max eda -B
Osli-1,1	23	2	9	7.972	5.148
Txvr-2,3	22	1	2	6.202	3.239
Mwmu-3,2	19	1	3	4.296	3.599
Ndmq-4,5	21	3	3	2.4	2.147
Kobo-5,4	22	1	2	1.304	0.6711
Quam6,6	20	1	3	0.574	0.4457

Table 4.1 EDA observation for female

name	age	experience	Motion sickness score	Max EDA	Max eda -B
Pity (1,1)	23	5	0	28.82	19.11
Ozdm(2,2)	20	0	4	15.49	13.30
Wjii(3,3)	23	0	10	8.504	5.21
Jfbm(4,7)	22	0	4	9.460	2.569
Qhop(5,4)	18	0	12	5.123	3.995
Agzv_1(6,6)	19	0	9	4.835	3.024
Ozdm_1(7,5)	19	0	5	6.142	4.208

Table 4.2 EDA observation for Male

Similar to EDA, the HR values of female and male participants are analysed separately for baseline and distracted events and is represented in the Figure 4.7 and Figure 4.8. The observations are analysed from same aspects like age, experience, motion sickness score and gender.

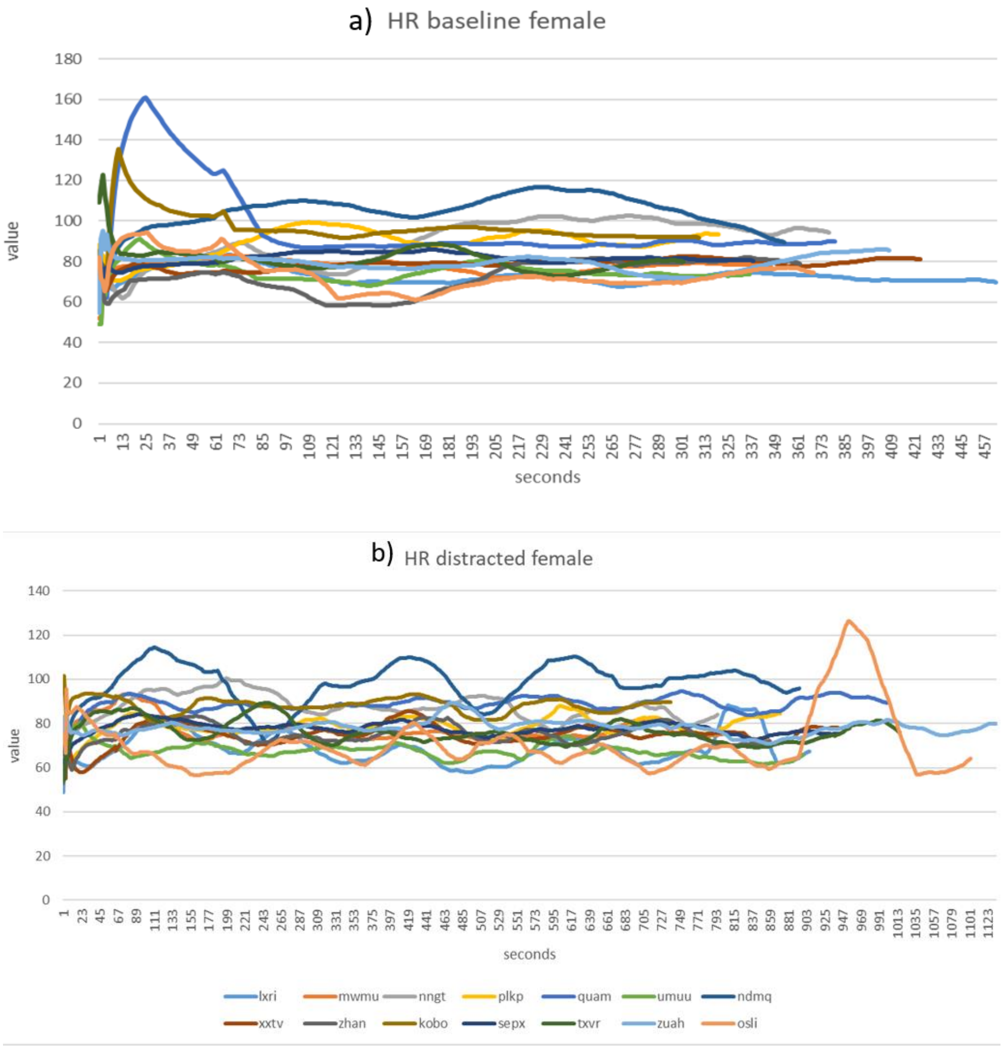


Figure 4.7 a) Baseline HR values of Female **b)** Distracted HR values of female

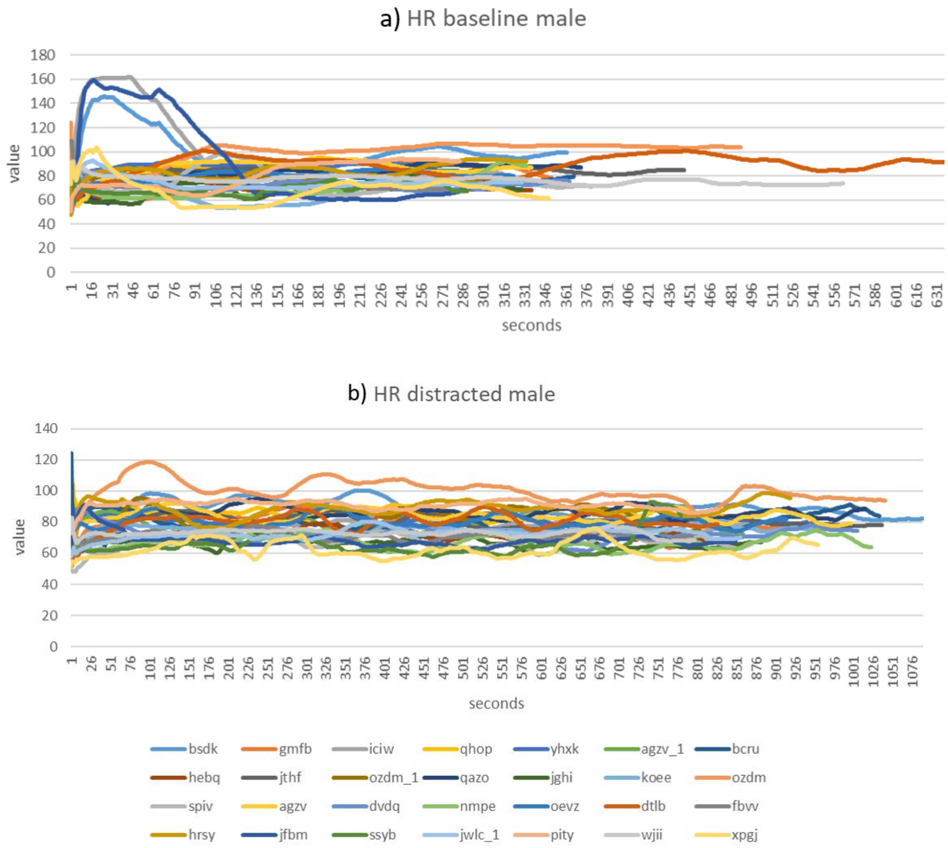


Figure 4.8 a) Baseline HR values of male **b)** Distracted HR values of male

The value of HR for distracted is higher than that of baseline. The initial twenty seconds of the baseline event was not considered because the baseline event is measured first. It takes time for participants to get used to sensors and there would be adjustments made which may give us absurd values. With the Onset of driving, there tends to be stress caused in the arteries, due to which we get high HR peaks in the baseline. But as time increases, the baseline rate gets normal. Therefore, on an average, the range of HR during distracted task is higher than baseline which can be seen in an example shown in Figure 4.9. The gender of the participants do not have much influence on HR values. But the experience and MSSQ do have impact on HR variation between baseline and distracted.

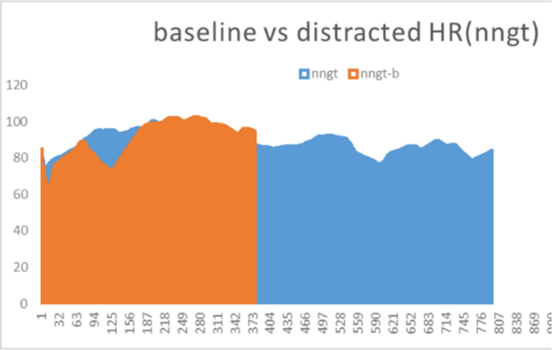


Figure 4.9 Baseline vs distracted HR

Compiling the observations above, while considering EDA and HR, the top peaks and fluctuations are seen in participants with one or less than one year of experience (Figure 4.10).

The range of HR and EDA is more or less the same for male and female participants of the same age. When considering the MSSQ score and the physiological factors, EDA (Figure 4.11) and HR (Figure 4.12) slightly increase when MSSQ score increases. There is a mild temperature decrease in participants as the MSSQ score increases, as shown in Figure 4.13. One particular participant (Osli) showed deviation from these observations. She has experience of more than two years and also has less MSSQ score compared to others who have higher values of EDA and HR while distraction which can be observed through the graphs. This can be answered from the observations from the DBQ and TLX obtained from the participants before and after the experiment respectively.

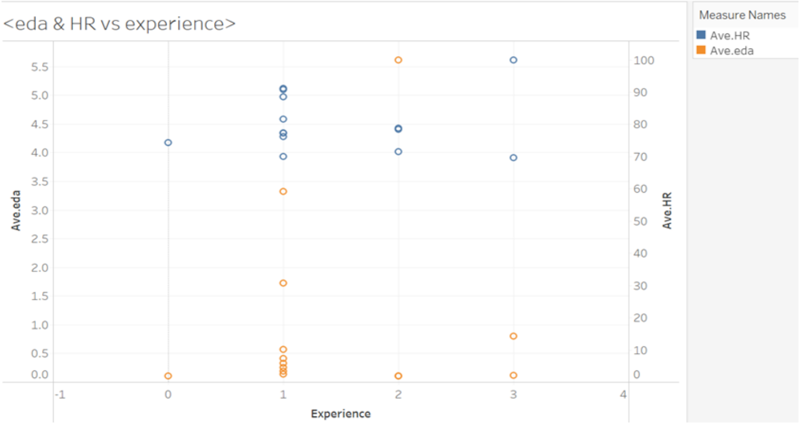


Figure 4.10 EDA and HR vs experience

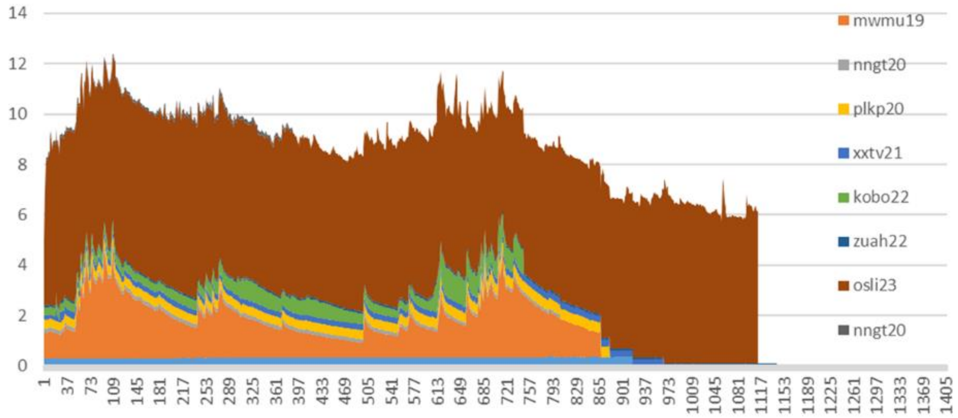


Figure 4.11 Increase in average EDA for participants with higher MSSQ score

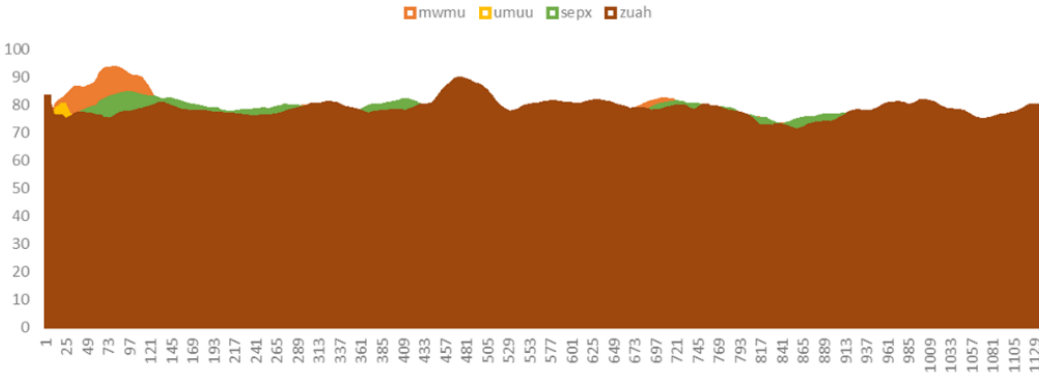


Figure 4.12 Increase in average HR of participants with higher MSSQ score

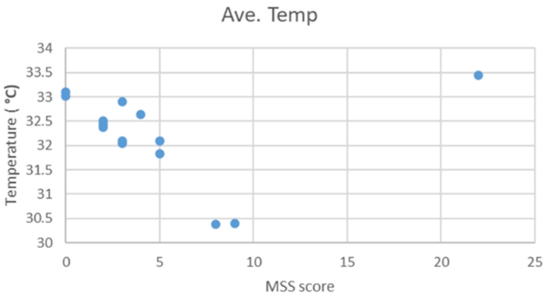


Figure 4.13 Average temperature VS MSSQ score

DBQ obtained from the participants shows that the person with high peaks in HR had scored more than the average score of all the participants. The results gathered from this questionnaire show that most of them were impatient while driving, crossed the intersection through, misread the signals and mostly ignored the speed limits. That particular participant Osli mentioned previously has the same pattern. Her score for DBQ was 19/25, which was above average. A similar observation could be seen in a few other participants whose HR and EDA peaks were higher.

Considering the NASA TLX could reveal more about their behavioral responses. It can also be used to evaluate how the participants feel with and without distraction during the task. Of all the traits in the Load index, the majority of these participants experienced high mental demand, temporal demand, effort and frustration, which could be seen in the Figure 4.15. It is also seen that the rating of these parameters vary with and without distraction task through the Figure 4.14 and Figure 4.15. The rating is less for the driving task without distraction. When the distraction occurs, participants tend to have an extra load which results in a higher rating of these parameters.

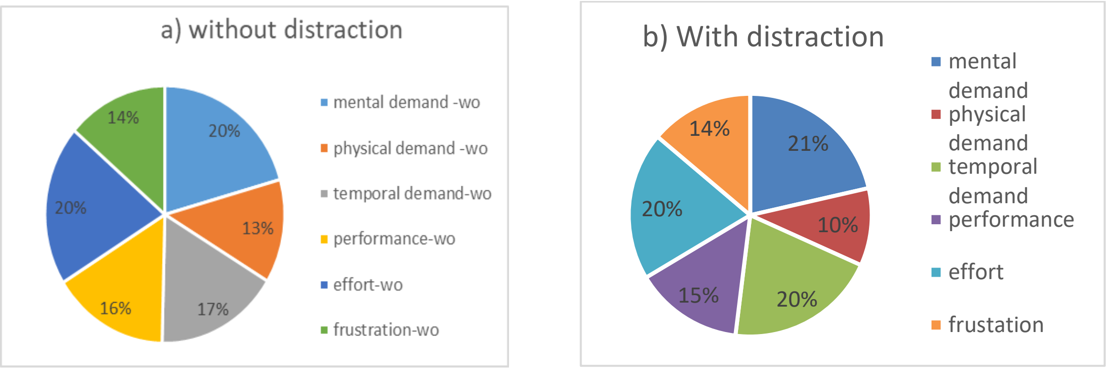


Figure 4.14 Cumulative representation of NASA TLX parameters with and without distraction

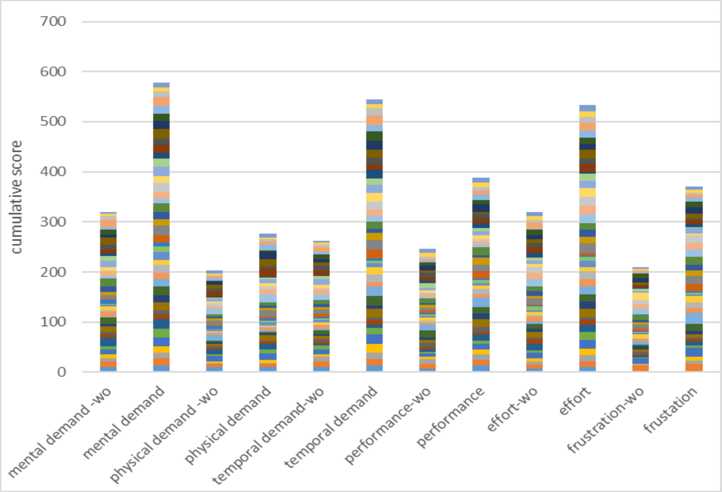


Figure 4.15 cumulative score of NASA TLX for all participants

The participant we discussed above had all the parameters above average level. It was seen that her mental demand was 18 and frustration was 17 on a scale of 21. From DBQ analysis, it was seen that she has more statements crossed like being impatient while driving, failing to notice pedestrians while taking a turn and a few more similar to such activities. These observations from DBQ and TLX can give us an insight into why this participant stood out from the rest of the participants in terms of having peaks in EDA and HR though she has experience and less MSSQ score.

4.3 Insights obtained

From the study, it could be seen that experience has impact on EDA and HR. Younger drivers are inexperienced and are more likely to engage in a risky driving activity. They tend to get stressed when distracted and find it challenging to handle the situation. This can be supported by the observations from DBQ and NASA TLX.

The EDA and HR increase as the motion sickness score increases. It is associated with the Sympathetic Nervous System (SNS), a part of the Autonomous Nervous system (ANS). SNS is responsible for stimulating the body for a fight-or-flight response. From the literature, it is known that motion sickness affects physiological factors. Therefore, HR increases as a response from SNS to overcome the situation. The same applies to EDA as well.

The physiological responses like heart rate, sweating, and digestion come under ANS. This regulates and coordinates the activities that are involuntary or have no control and are done without even noticing about it. The SNS, as stated above, controls the reflexes needed for emergency situations (flight & fight) where the body needs an alert. Therefore, when the participant gets distracted, the SNS activates the survival response by increasing the sweat glands' activity and heart rate. This proves why EDA and HR increase in distraction more than baseline.

There is a mild decrease in temperature as the motion sickness score increases because motion sickness attenuates the vasoconstrictor response in the skin, which leads to core cooling. This increases heat loss and therefore the body temperature decreases.

The observations from the questionnaire obtained from the participants show that the participants with higher motion sickness tend to have higher values of EDA and HR during distracted events. A few exceptional conditions of the participants can be answered from their responses obtained through DBQ and TLX. These questionnaires help us know their driving behavior history and how the additional distraction tasks would affect them.

Chapter 5

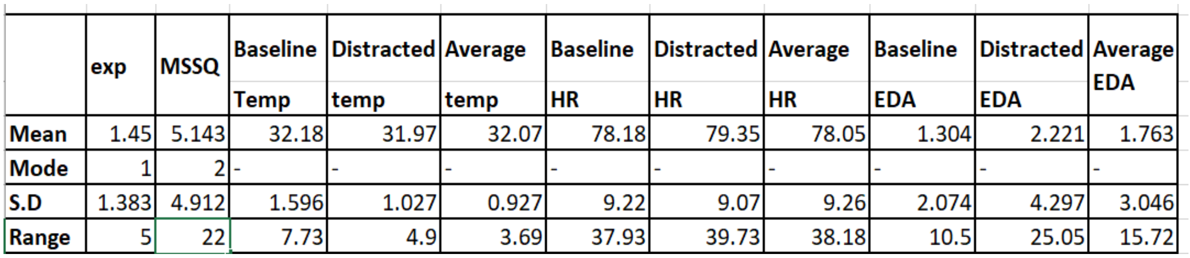
Results and discussion

The observations from the previous chapter gives us insight about how the physiological factors vary with other parameter and also between baseline and distracted measurements. The hypothesis can be defined with the observation obtained. Of all three physiological factors, EDA and HR has increased during distracted event when compared with baseline. When taking experience as the parameter, the EDA and HR decreases with increase in experience. Therefore, the null hypothesis and alternative hypothesis for this condition can be stated as: H_0: EDA and HR are not affected by experience of the participants & H_A: EDA & HR are significantly affected by the experience of the participants.

All three physiological factor are affected by MSSQ score which was observed in section 4.2. The null hypothesis for this case would be H_0: The physiological factors do not change with MSSQ score and the alternative hypothesis would be H_A: The physiological factors do change with MSSQ score. Other than the parameters discussed above, the results obtained through the questionnaires from the participants gives us the behavioral aspects of the participants when getting distracted [section 4.3].

5.1 Results

There were 42 participants. The experience range of the participants is 5 with a mean of 1.45 and Standard deviation of about 1.383. Therefore, 68% of the participants have experience of 1.45±1.383. Most of the participants have 1 year of experience (mode=1). When considering MSSQ score, the mean score was 5.143 and most participants have score of 2 (mode=2) but the standard deviation was higher. From the Table 5.1 the mean value of EDA and HR are higher in distracted event when compared to baseline event. While the mean of temperature is less in distracted when compared to baseline.



	exp	MSSQ	Baseline Temp	Distracted temp	Average temp	Baseline HR	Distracted HR	Average HR	Baseline EDA	Distracted EDA	Average EDA
Mean	1.45	5.143	32.18	31.97	32.07	78.18	79.35	78.05	1.304	2.221	1.763
Mode	1	2	-	-	-	-	-	-	-	-	-
S.D	1.383	4.912	1.596	1.027	0.927	9.22	9.07	9.26	2.074	4.297	3.046
Range	5	22	7.73	4.9	3.69	37.93	39.73	38.18	10.5	25.05	15.72

Table 5.1 Descriptive analysis

The factorial anova for EDA, HR and temperature between their baseline and distracted values is shown in Table 5.2 below. The null hypothesis is stated as H_0: There is no significant difference between the baseline and distracted values of these factors and alternative hypothesis is H_A: there is significant difference between Baseline and distracted data. The result shows that the null hypothesis is accepted for all three physiological factor.

	B.EDA vs D.EDA	**B.HR vs D.EDA**	**B.Temp vs D.Temp**
F value	1.5535	0.3472	0.5001
P value	0.2162	0.5573	0.4815

Table 5.2 Baseline vs Distracted (B-Baseline, D-Distracted)

Then, the ANOVA test is performed for HR, EDA and Temperature with experince, considering significance level of α =0.05. The result reveals that HR and Temperature are significantly affected by experience (97% and 99%) which can be seen from the effect size in Table 5.3. The average value of EDA and HR is also higher for group with less experience. For participants with zero experience HR and EDA values are 82.781 and 2.846 respectively which decreases down to 70.105 and 1.773 for participants with higher experince of four and five years.

Experience with	EDA	HR	Temperature
F value	1.226	2997.651	14207.6
P value	0.272	3.54E^{-}65	1.14E^{-}93
Effect size	0.014	0.974	0.994

Table 5.3 Anova test for experience

When ANOVA test is done for MSSQ score against HR, EDA and temperature, P-value is ≤ 0.05 for all of them. The effect size is also more for HR and Temperature which can be seen from the Table 5.4.

MSSQ with	EDA	HR	Temperature
F value	14.361	2055.22	1219.03
P value	0.00028	8E^{-}59	5.47E^{-}51
Effect size	0.149	0.963	0.937

Table 5.4 : Anova for MSSQ and physiological factors

In order to assess the monotonic relationship between the parameters, Spearman's Rho calculation is done. This test can define the strength and direction of the relationship between two parameters. The negative sign of 'r_s' denotes that there is decrease in trend of the second parameter when compared against the first parameter. Table 5.5 shows, with increase in Experience the HR and EDA value slightly decreases. When MSSQ score is considered, the spearman's test shows decreasing trend with Temperature and increasing trend with EDA.

Spearman's test	Experience vs HR	Experience vs EDA	MSSQ vs HR	MSSQ vs EDA	MSSQ vs Temp
'r_s' value	-0.45398	-0.13097	-0.127	0.16792	-0.19740
P value	0.00253	-0.40839	0.2878	0.42286	0.21112

Table 5.5 : Spearman's test

Hypothesis testing is done with Pearson 'r'. This can be defined to imply the relationship between the independent variables experience and MSSQ and dependent variables EDA, HR and Temperature. Pearson's r test is done to check whether Experience and MSSQ have significant relationship with EDA, HR and temperature, in same way as obtained through exploration of the data.

The null hypothesis and alternative hypothesis can be defined. We expect negative relationship between experience Vs HR, experience vs EDA and MSSQ vs temperature. Therefore, the hypothesis for them can be defined as H_0: $\rho \geq 0$ & H_A: $\rho < 0$.

At the same time, we expect positive relationship between MSSQ vs EDA and MSSQ vs HR. Therefore, the hypothesis for such case is defined as H_0: $\rho \leq 0$ & H_A: $\rho > 0$. Considering significance level, $\alpha = 0.05$, df =41 we get $r_{crit} = 0.304$.

Pearson 'r' test	**Experience vs HR**	**Experience vs EDA**	**MSSQ vs HR**	**MSSQ vs EDA**	**MSSQ vs Temperature**
'r' value	-0.4347	0.2344	-0.2019	-0.0364	-0.1099
P value	0.00458	0.1351	0.1995	0.820	0.4880

Table 5.6 Pearson's test

The '- 'sign indicates the negative correlation between the parameters. From the above Table 5.6, it is seen that the experience vs heart rate and MSSQ vs temperature has negative correlation. Therefore, the null hypothesis is rejected in these cases. While other parameters have opposite observation which means null hypothesis cannot be rejected.

When considering the workload of the participants with and without distractions, the hypothesis stated was proven with statical significance. This could be seen from the p-values in the table below. The P value is ≤ 0.05 for all of them. Therefore, the workload parameters are higher for the task with distraction when compared to one without distraction.

	Mental	**physical**	**Temporal**	**performance**	**effort**	**frustration**
F value	58.6383	5.3698	72.6754	26.2268	44.0914	18.0361
P value	3.32E-11	0.02298	6.34E-13	1.97E-6	3.17E-9	5.68E-5

Table 5.7 Anova for Workload with and without distractions

The first hypothesis between baseline and distracted values of HR, EDA and Temperature accepts Null hypothesis since there is not much significant difference. In the second hypothesis for Experience and the factors, HR and Temperature accepts Alternative hypothesis which shows that experience has correlationship with them, while EDA accepts Null hypothesis. For the third hypothesis between MSSQ and factors, HR, EDA and Temperature accepts Alternative hypothesis proving that there is correlation between the factors and MSSQ score. Finally, when considering Workload with and without distraction, the Alternative hypothesis is accepted which shows that there is increase in workload with addition of distraction.

5.2 Discussion

The exploratory analysis on comparing the values of physiological factors during baseline and distracted task shows that the EDA and HR increases during distracted task when compared to baseline [Section 4.2]. The mean obtained from the data also supports this observation [Table 5.1]. While the Anova test reveal that they are not statistically significant i.e., there is not much significant difference between baseline and distracted values of EDA, HR and Temperature among the participants. This not as stated in previous works which says that the Distracted values are significantly higher than that of the baseline values.

When considering the experience, the exploratory graphs in the section 4.2 show us that EDA and HR remains high for the participants with less experience. This is same as expected through the literature review in section 2. It is statistically significant for HR and has very less significance when EDA is considered as seen in Table 5.3.

The Effect of MSSQ score on EDA, HR and Temperature obtained from exploratory analysis [Section 27] remains statistically significant which can be seen in Table 5.4. The EDA, HR and Temperature all have P-value ≤ 0.05, which shows they are statistically significant with good effect size. The Literature review of previous works also states that the EDA and HR are highly correlated to motion sickness.

In order to know the correlation and linearity of physiological factors with experience and MSSQ, correlation analysis was done Table 5.6. The result shows that there is negative correlationship between HR and experience which is statistically significant as well. The workload of the participants also increases with distraction which can be seen in the Table 5.7 which is again the expected result from the previous studies.

Chapter 6

Conclusion

The study attempts to know the effect and impact of physiological factors during distracted driving among young drivers aged 16-23. The physiological factors like EDA, HR and temperature are collected through the E4 empatica Wrist band during a simulator study which involves driving in different scenarios with and without distraction. The participants were also asked to fill questionnaires before and after the experiment.

When these three physiological factors are analysed in terms of baseline and distracted values, the exploratory from section 4.2 and descriptive analysis from section 5.1 shows that the EDA and HR tend to increase their values during distraction which was discussed in literature study [Section 2.1.3]. While their statistical significance remains very less. The parameters like age, gender, and experience were considered to evaluate their correlations with the EDA and HR. It was observed that the participants with less experience had higher values of HR [Section4.2 and 5.1].

The MSSQ score has impact on all three physiological factors during exploratory analysis [Section4.2]. The MSSQ score, when analysed statistically as in section 5.1, reveals a positive relationship with EDA and HR as discussed in the literature [Section 2.1.3] and negative relationship with temperature.

The DBQ and NASA TLX also give us insight into how the driver behavior and the load caused by the distraction are related to it. The participants with higher DBQ have more mental demand, temporal demand and frustration, which leads to an increase in HR and EDA as a survival response to overcome the distraction, which is activated by the Sympathetic Nervous System [Section 4.2 and 4.3].

The insights obtained through the work will be a great consideration while designing a distraction mitigation system required for safe driving.

6.1 Limitations

Limitations of this analysis include simulator study & scenarios that are used to collect the data. The scenarios used in the study were in good daylight condition and there were only six scenarios. While in real life, the distraction may happen at nighttime and also in various other scenarios. The data was collected in a realistic environment but in simulator-based scenarios. Though there is much prior research done for driver distraction using a simulator, there will always be a difference in driver behavior and the way physiological factor varies between real-time, on-road environment and simulator environment [101]. Therefore, the observations and findings discussed in this thesis cannot be generalized. This also varies and relies on the instrument or sensor we use to collect data since it determines the quality of the data to be analyzed. For example, an important limitation of is that EDA is affected by ambient temperature and humidity [56].

Another limitation of this thesis would be working on the data which was collected already because any additional insights or inputs if needed, cannot be obtained again while working. Heart rate variability can also be used in future studies since it measures specific changes in time between successive heart rate. Further, trend analysis can be done if the data was collected between distracted and non- distracted events. The physiological data could have collected for distracted and non-distracted condition of the drivers for a scenario which would have given us more insights. Also, getting data from more participants would contribute to more accurate results.

These limitations can be reduced when the study is a naturalistic driving and with better sensors to collect quality data, considering more participants in the study and also considering various other real-world scenarios, which include nighttime drives, would be much more reliable to analyze and implement in advancing automobiles in the real-time world.

6.2 Future works

The insights from this study can be taken into consideration while designing or developing a distraction mitigation system. Distraction mitigation system can include delivery of a gentle warning when there are peaks in the physiological factors and when the value of EDA and HR is above normal range. By measuring physiological signal an automatic management of non-critical information system in the vehicle like radio, music player can be done when the driver is more distracted than allowed for the environment in which they drive [57][98]. Even cellphone calls may be diverted directly to voice mails when the driver is at high stress condition.

A driving simulator study was also conducted to evaluate whether real-time feedback on driver's state can influence the driver's interaction with distraction causing IVIS. The result of this study shows that the feedback about the drivers on their state can actually make a positive impact [100]. While thinking about this, we should also make sure that these mitigation system doesn't provide additional distraction or stress to the drivers [98][99]. The contract, SAfety VEhicle using adaptive Interface Technology (SAVE-IT) was designed to mitigated distraction with effective countermeasures and to enhance the effectiveness of safety warning system [56]. The result of this contract shows that the safety warning system can significantly reduce the distraction related crashes.

Therefore, the Impact and effect of the physiological factor plays a major role in developing a distraction mitigation system which is considered as the future work of this study.

References

[1] World Health Organization. (n.d.). *Global status report on road safety 2015*.

[2] Highway Traffic Safety Administration, N., & Department of Transportation, U. (2020). *Distracted Driving 2020*.

[3] Road Safety Canada Consulting., Canada. Transport Canada., & Canadian Electronic Library. (2012). *Road safety in Canada*. Transport Canada.

[4] Gemmill, I., Arra, I., Carew, M., Gardner, C., Gould, R., Spruyt, M., & Lu, D. (n.d.). *PREVENTING ROAD TRAFFIC DEATHS AND INJURIES Position Paper Road Safety Working Group, COMOH*.

[5] Sherif Ishak, by, Osama Osman, P. A., Codjoe, J., & Jenkins Sogand Karbalaieali Matthew Theriot Peter Bakhit, S. (n.d.). *Exploring Naturalistic Driving Data for Distracted Driving Measures*.

[6] McDonald, A. D., Ferris, T. K., & Wiener, T. A. (2020). Classification of Driver Distraction: A Comprehensive Analysis of Feature Generation, Machine Learning, and Input Measures. *Human Factors, 62*(6), 1019–1035.

[7] Fernández, A., Usamentiaga, R., Carús, J. L., & Casado, R. (2016). Driver distraction using visual-based sensors and algorithms. In *Sensors (Switzerland)* (Vol. 16, Issue 11). MDPI AG.

[8] Pragati Bhagwanrao, M., Potpelwar, R. S., & Professor, A. (2020). *Driver Distraction Detection and Classification using Machine Learning*. www.ijcrt.org

[9] Saini, V., & Saini, R. (n.d.). *Driver Drowsiness Detection System and Techniques: A Review*.

[10] Zeng, Z., Huang, Z., Leng, K., Han, W., Niu, H., Yu, Y., Ling, Q., Liu, J., Wu, Z., & Zang, J. (2020). Nonintrusive Monitoring of Mental Fatigue Status Using Epidermal Electronic Systems and Machine-Learning Algorithms. *ACS Sensors, 5*(5), 1305–1313.

[11] Lu, Y., Fu, X., Lu, C., Guo, E., Tang, F., Zhu, J., & Li, H. (2020). Effects of route familiarity on drivers' psychological conditions: Based on driving behaviour and driving

environment. *Transportation Research Part F: Traffic Psychology and Behaviour*, *75*, 37–54.

[12] Qian, C., Li, Y., Zuo, W., & Wang, Y. (n.d.). *Analysis of Driving Safety and Cellphone Use Based on Social Media*.

[13] *Use of Electronic Communication Devices by Canadian Drivers: Combined Urban/Rural Sites Survey of Electronic Communication Device Use by Canadian Drivers in Urban/Rural Areas Combined*. (2016).

[14] Musabini, A., & Chetitah, M. (2020). *Heatmap-Based Method for Estimating Drivers' Cognitive Distraction*.

[15] Durbin, D. R., Mcgehee, D. v, Fisher, D., & Mccartt, A. (n.d.). *Special Considerations in Distracted Driving with Teens*.

[16] Chan E, Pradhan AK, Pollatsek A, et al. *Are Driving Simulators Effective Tools for Evaluating Novice Drivers' Hazard Anticipation, Speed Management, and Attention Maintenance Skills?* Transp Res Part F Traffic Psychol Behav 13: 343-353, 2010.

[17] Chen L, Baker SP, Braver ER, et al. *Carrying Passengers as a Risk Factor for Crashes Fatal to 16- and 17-Year-Old Drivers*. JAMA 283: 1578-1582, 2000.

[18] Chen LH, Baker SP, Li GH. *Graduated Driver Licensing Programs and Fatal Crashes of 16-Year-Old Drivers: A National Evaluation*. Pediatrics 118: 56-62, 2006.

[19] Crundall D, Chapman P, Trawley S, et al. *Some Hazards Are More Attractive Than Others: Drivers of Varying Experience Respond Differently to Different Types of Hazard.* Accid Anal Prev 45: 600-609, 2012.

[20] Curry AE, Hafetz J, Kallan MJ, et al. *Prevalence of Teen Driver Errors Leading to Serious Motor Vehicle Crashes*. Accid Anal Prev 43: 1285-1290, 2011.

[21] Curry AE, Mirman JH, Kallan MJ, et al. *Peer Passengers: How Do They Affect Teen Crashes?* J Adolesc Health 50: 588-594, 2012.

[22] Hamilton BC, Arnold LS, Tefft BC. *Distracted Driving and Perceptions of Hands-Free Technologies: Findings from the 2013 Traffic Safety Culture Index*. AAA Foundation for Traffic Safety, Washington, DC, 2013.

[23] Insurance Institute for Highway Safety. Unpublished Analysis of 2008 data from the U.S. Department of Transportation's National Household Travel Survey: *General Estimates System, and Fatality Analysis Reporting System.* Arlington, VA, unpublished data.

[24] Insurance Institute for Highway Safety. *Teenagers: Driving carries extra risk for them.* Available at: http://www.iihs.org/iihs/topics/t/teenagers/topicoverview.

[25] Jaccard J, Blanton H, Dodge T. *Peer Influences on Risk Behavior: An Analysis of the Effects of a Close Friend*. Dev Psychol 41: 135-147, 2005.

[26] Lee, SE, Olsen, ECB, Simons-Morton, BG. *Eyeglance Behavior of Novice Teen and Experienced Adult Drivers.* Transportation Research Record: Journal of the Transportation Research Board, No 1980. Transportation Research Board of the National Academies; Washington, D.C.: 2006.; p. 57-64.

[27] Lee SE, Klauer SG, Olsen ECB et al. *Detection of Road Hazards by Novice Teen and Experienced Adult Drivers*. Transportation Research Record2008;2078: 26-32.

[28] Lee SE, Simons-Morton BG, Klauer SE, et al. *Naturalistic Assessment of Novice Teenage Crash Experience*. Accid Anal Prev 43: 1472-1479, 2011.

[29] McKnight AJ, McKnight AS. *Young Novice Drivers: Careless or Clueless?* Accid Anal Prev 35: 921-925, 2003.

[30] Olsen ECB, Lee SE, Simons-Morton BG. *Eye Movement Patterns for Novice Teen Drivers.Does 6 Months of Driving Experience Make a Difference?* Transportation Research Record 2007, pg 8-14.

[31] Ouimet MC, Pradhan AK, Simons-Morton BG, et al. *The Effect of Male Teenage Passengers on Male Teenage Drivers: Findings from a Driving Simulator Study*. Accid Anal Prev 58: 132-139, 2013.

[32] Pradhan AK, Hammel KR, DeRamus R, et al. *Using Eye Movements to Evaluate Effects of Driver Age on Risk Perception in a Driving Simulator*. Hum Factors 47: 840-852, 2005.

[33] Simons-Morton B, Ouimet MC, Zhang Z, et al. *Crash and Risky Driving Involvement among Novice Adolescent Drivers and Their Parents*. Am J Public Health 101: 2362-2367, 2011a.

[34] Simons-Morton BG, Ouimet MC, Zhang Z, et al. *The Effect of Passengers and Risk-Taking Friends on Risky Driving and Crashes/near Crashes among Novice Teenagers*. J Adolesc Health 49: 587-593, 2011b.

[35] Simons-Morton BG, Guo F, Klauer SG et al. *Keep your eyes on the road: young driver crash risk increases according to the duration of distraction*. J Adol Health, in press.

[36] Tefft BC, Williams AF, Grabowski JG. *Teen Driver Risk in Relation to Age and Number of Passengers*, United States, 2007–2010. Traffic Inj Prev 14: 283-292, 2012.

[37] Tison J, Chaudhary N, Cosgrove L. *National Phone Survey on Distracted Driving Attitudes and Behaviors*. National Highway Traffic Safety Administration, Washington, DC, 2011.

[38] E. J. C. Nacpil, Z. Wang, and K. Nakano, "Application of Physiological Sensors for Personalization in Semi-Autonomous Driving: A Review," IEEE Sens. J., vol. 21, no. 18, pp. 19662–19674, 202.

[39] D. D. Heikoop, J. C. F. de Winter, B. van Arem, and N. A. Stanton, "Effects of platooning on signal-detection performance, workload, and stress: A driving simulator study," *Appl. Ergonom.*, vol. 60, pp. 116–127, Apr. 2017.

[40] T. Heine, G. Lenis, P. Reichensperger, T. Beran, O. Doessel, and B. Deml, "Electrocardiographic features for the measurement of drivers' mental workload," *Appl. Ergonom.*, vol. 61, pp. 31–43, May 2017.

[41] C. Dijksterhuis, K. A. Brookhuis, and D. De Waard, "Effects of steering demand on lane keeping behaviour, self-reports, and physiology. A simulator study," *Accident Anal. Prevention*, vol. 43, no. 3, pp. 1074–1081, May 2011

[42] [42] K. A. Brookhuis, C. J. G. van Driel, T. Hof, B. van Arem, and M. Hoedemaeker, "Driving with a congestion assistant; mental workload and acceptance," *Appl. Ergonom.*, vol. 40, no. 6, pp. 1019–1025, Nov. 2009.

[43] R. Zheng, S. Yamabe, K. Nakano, and Y. Suda, “Biosignal analysis to assess mental stress in automatic driving of trucks: Palmar perspiration and masseter electromyography,” *Sensors*, vol. 15, no. 3, pp. 5136–5150, Mar. 2015.

[44] A. Affanni, R. Bernardini, A. Piras, R. Rinaldo, and P. Zontone, “Driver’s stress detection using skin potential response signals,” *Measurement*, vol. 122, pp. 264–274, Jul. 2018.

[45] H. Kawanaka, M. Miyaji, M. S. Bhuiyan, and K. Oguri, “Identification of cognitive distraction using physiological features for adaptive driving safety supporting system,” *Int. J. Veh. Technol.*, vol. 2013, 2013

[46] J. M. D. Bruxella and J. K. Kanimozhi, “A Review on identification of the Drivers ’ Distraction while driving,” vol. XI, no. 1676, pp. 1676–1690, 2019.

[47] Y. Liang, M. L. Reyes, and J. D. Lee, “Real-time detection of driver cognitive distraction using support vector machines,” *IEEE Trans. Intell. Transp. Syst.*, vol. 8, no. 2, pp. 340–350, 2007

[48] J. M. Dallfin Bruxella and J. K. Kanimozhi, “Driver Distraction Recognition Using Convex-Hull and Geometry Based Support Vector Machine Classifier,” vol. VIII, no. X, pp. 237–269.

[49] L. R. Quitadamo *et al.*, “Support vector machines to detect physiological patterns for EEG and EMG-based human-computer interaction: A review,” *J. Neural Eng.*, vol. 14, no. 1, pp. 1–35, 2017.

[50] A. Misra, “Detection of Driver Cognitive Distraction Using Machine Learning Methods,”pp.1–82,2020.

[51] A. D. McDonald, T. K. Ferris, and T. A. Wiener, “Classification of Driver Distraction: A Comprehensive Analysis of Feature Generation, Machine Learning, and Input Measures,” *Hum. Factors*, vol. 62, no. 6, pp. 1019–1035, 2020,

[52] T. Wiener, “*PREDICTING DRIVER DISTRACTION : AN ANALYSIS OF MACHINE LEARNING ALGORITHMS AND INPUT MEASURES*,” no. May, 2018.

[53] Kahneman, D.; Tursky, B.; Shapiro, D.; Crider, A. “Pupillary, heart rate, and skin resistance changes during a mental task”. *J. Exp. Psychol.* 1969, 79, 164–167.

[54] Heeman, P.A.; Meshorer, T.; Kun, A.L.; Palinko, O.; Medenica, Z. “Estimating cognitive load using pupil diameter during a spoken dialogue task. In Proceedings of the 5th International Conference on Automotive User Interfaces and Interactive Vehicular Applications”, *Eindhoven, The Netherlands,* 27–30 October 2013; pp. 242–245.

[55] Pfleging, B.; Fekety, D.K.; Schmidt, A.; Kun, A.L.” A Model Relating Pupil Diameter to Mental Workload andLighting Conditions”. In Proceedings of the 2016 *CHI Conference on Human Factors in Computing Systems*, San Jose, CA, USA, 7–12 May 2016; pp. 5776–5788.

[56] J. D. Lee, M. Rheyes, and D. V McGehee, “A literature review of cognitive distraction,” *SAVE-IT Saf. Veh. using Adapt. interface Technol. (Task 5),* no. November, p.69,2004.

[57] J. A. Healey and R. W. Picard, “Detecting stress during real-world driving tasks using physiological sensors,” *IEEE Trans. Intell. Transp. Syst.*, vol. 6, no. 2, pp. 156–166, 2005

[58] E. Cannon, C. Dalton, P. Greenberg, A. Jones, and D. Truehl, “The Effect of Distractors on Physiological Stress During a Test,” *Physiology*, vol. 435, no. 3.

[59] K. Kashihara, "A brain-computer interface for potential non-verbal facial communication based on EEG signals related to specific emotions," *Frontiers in Neuroscience,* vol. 8, pp. 1-12, 2014.

[60] R. Carabalona, F. Grossi, A. Tessadri, P. Castiglioni, A. Caracciolo, and I. de Munari, "Light on! Real world evaluation of a P300-based brain-computer interface (BCI) for environment control in a smart home," *Ergonomics,* vol. 55, pp. 552-563, 2012.

[61] R. N. Khushaba, S. Kodagoda, D. Liu, and G. Dissanayake, "Muscle computer interfaces for driver distraction reduction," *Computer Methods and Programs in Biomedicine,* vol. 110, pp. 137-149, 2013.

[62] A. Tanaka and R. B. Knapp, "Multimodal Interaction in Music Using the Electromyogram and Relative Position Sensing," presented at the Conference on New interfaces for musical expression (NIME '02), 2002.

[63] A. Kumar, G. Chattree, and S. Periyasamy, “Smart Healthcare Monitoring System,” Wirel. Pers. Commun., vol. 101, no. 1, pp. 453–463, 2018

[64] Farin NJ, Sharif SM, Mobin I. “An intelligent sensor based system for real time heart rate monitoring (HRM)”. Intell Control Autom 2016;7:55.

[65] 2. Shao D. “A Proposal of a Mobile Health Data Collection and Reporting System for the Developing World”, Master Thesis Project, Spring; 2012.

[66] Madhumathi RM, Jagadeesan A, Kaushik S. “Healthcare Monitoring System using Body Sensor Network”, International Conference On Engineering Innovations and Solutions (ICEIS); 2016.

[67] A. I. Wijaya, A. S. Prihatmanto, and R. Wijaya, “Shesop Healthcare: Stress and influenza classification using support vector machine kernel,” 2016.

[68] B. Farnsworth, “Heart Rate Variability - What This Measure Means For Emotions”, imotions.com,2022

[69] O. Dehzangi, V. Rajendra, and M. Taherisadr, “Wearable driver distraction identification on-the-road via continuous decomposition of galvanic skin responses,” *Sensors (Switzerland)*, vol. 18, no. 2, pp. 1–16, 2018.

[70] B. Farnsworth, “GSR and Emotions: What Our Skin Can Tell Us About How We Feel",imotions.com,2018.

[71] Blechert, J., Lajtman, M., Michael, T., Margraf, J., Wilhelm, F.H, “Identifying anxiety states using broad sampling and advanced processing of peripheral physiological information”. Biomedical Sciences Instrumentation 42, 136-141, 2006

[72] Hess, U., Kappas, A., McHugo, G.J., Lanzetta, J.T., Kleck, R.E, The facilitative effect of facial expression on the self-generation of emotion,1992.

[73] S. Taamneh et al., “A multimodal dataset for various forms of distracted driving,” Sci. data, vol. 4, p. 170110, 2017

[74] S. Ahangari, M. Jeihani, and A. Dehzangi, “A Machine Learning Distracted Driving Prediction Model,” ACM Int. Conf. Proceeding Ser., no. August, 2019

[75] P. N. Cañas, J. D. Ortega, M. Nieto, and O. Otaegui, “Detection of distraction-related actions on DMD: An image and a video-based approach comparison,” VISIGRAPP 2021 - Proc. 16th Int. Jt. Conf. Comput. Vision, Imaging Comput. Graph. Theory Appl., vol. 5, no. Visigrapp, pp. 458–465, 2021

[76] O. Dehzangi, V. Sahu, V. Rajendra, and M. Taherisadr, “GSR-based distracted driving identification using discrete & continuous decomposition and wavelet packet transform,” Smart Heal., vol. 14, no. November, p. 100085, 2019.

[77] Ciabattoni, L., Ferracuti, F., Longhi, S., Pepa, L., Romeo, L., & Verdini, F, “Real-time mental stress detection based on smartwatch” In Consumer electronics (ICCE), 2017 IEEE international conference on (pp. 110–111). IEEE,2017

[78] Dehzangi, O., & Taherisadr, M, “Driver distraction detection using mel cepstrum representation of galvanic skin responses and convolutional neural networks”, 24th international conference on pattern recognition (ICPR) (pp. 1481–1486). IEEE, 2018

[79] Dehzangi, O., Rajendra, V., & Taherisadr, M, Wearable driver distraction identification on-the-road via continuous decomposition of galvanic skin responses. Sensors, 18, 503, 2018.

[80] Nourbakhsh, N., Wang, Y., & Chen, F. “Gsr and blink features for cognitive load classification”, IFIP conference on human-computer interaction (pp. 159–166). Springer. 2013.

[81] Rajendra, V., & Dehzangi, O, “Detection of distraction under naturalistic driving using galvanic skin responses”, Wearable and implantable body sensor networks (BSN), IEEE 14th international conference on (pp. 157–160). 2017

[82] F. Pyre, “Analysis of physiological responses induced by motion sickness and its detection based on ocular parameters,” 2021.

[83] N. Duzmanska, P. Strojny, and A. Strojny, “Can simulator sickness be avoided? A review on temporal aspects of simulator sickness,” *Front. Psychol.*, vol. 9, no. NOV, 2018

[84] N. Milstein and I. Gordon, “Validating Measures of Electrodermal Activity and Heart Rate Variability Derived From the Empatica E4 Utilized in Research Settings That Involve Interactive Dyadic States,” *Front. Behav. Neurosci.*, vol. 14, no. August, pp. 1–13, 2020.

[85] Ying Wang, Bryan Reimer, Jonathan Dobres, and Bruce Mehler, “The sensitivity of different methodologies for characterizing drivers' gaze concentration under increased

cognitive demand”, Transportation research part F: traffic psychology and behaviour, 26:227-237, 2014.

[86] Pradipta Biswas and Gowdham Prabhakar. Detecting drivers' cognitive load from saccadic intrusion. Transportation research part F: traffic psychology and behaviour, 54:63-78, 2018

[87] “E4 wrist band User’S Manual © 2018 1,” pp. 1–32, 2018

[88] Foroogh Hajiseyedjavadi, Tingru Zhang, Ravi Agrawal, Michael Knodler, Donald Fisher, and Siby Samuel. Effectiveness of visual warnings on young drivers hazard anticipation and hazard mitigation abilities. Accident Analysis & Prevention, 116:41–52, 2018.

[89] Siby Samuel, Avinoam Borowsky, Shlomo Zilberstein, and Donald L Fisher. Minimum time to situation awareness in scenarios involving transfer of control from an automated driving suite. Transportation research record, 2602(1):115–120, 2016.

[90] Yalda Ebadi, Ganesh Pai Mangalore, and Siby Samuel. Impact of cognitive distractions on drivers’ anticipation behavior in vehicle-bicycle conflict situations. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting, volume 62, pages 1898–1902. SAGE Publications Sage CA: Los Angeles, CA, 2018.

[91] Willem Vlakveld, Matthew RE Romoser, Hasmik Mehranian, Frank Diete, Alexander Pollatsek, and Donald L Fisher. Do crashes and near crashes in simulator-based training enhance novice drivers’ visual search for latent hazards? Transportation research record, 2265(1):153–160, 2011.

[92] V. J. Gawron, "Human Performance Measure Handbook”.

[93] Battiste, V. and Bortolussi, M.R. Transport pilot workload: a comparison of two objective techniques. Proceedings of the Human Factors Society 32nd Annual Meeting. 150-154; 1988.

[94] Corwin, W.H., Sandry-Garza D.L., Biferno, M.H., Boucek, G.P., Logan, A.L., Jonsson, J.E., and Metalis, S.A. Assessment of crew workload measurement methods, techniques, and procedures. Volume I-Process, methods, and results (WRDC-TR-89-7006). Wright-Patterson Air Force Base, OH; 1989.

[95] Hancock, P.A. and Caird, J.K. Experimental evaluation of a model of mental workload. Human Factors. 35(3), 413-419; 1993.

[96] Hart, S.G. and Staveland, L.E. Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In P.A. Hancock and N. Meshkati (Eds) Human mental workload. Amsterdam: Elsevier, 1987.

[97] Jordan, P.W. and Johnson, G.L. Exploring mental workload via TLX: the case of operating a car stereo whilst driving. In A.G. Gale, I.D. Brown, CM. Haslegrave, H.W. Kruysse, and S.P. Taylor (Eds.). Vision in vehicles - IV. Amsterdam: North Holland; 1993.

[98] M. A. Regan et al., "On-road evaluation of Intelligent speed adaptation, following distance warning and seatbelt reminder systems: Final results of the TAG SafeCar project," Monash Univ. Accid. Res. Cent. Reports, vol. 253, no. September, p. 270, 2006.

[99] M. Maltz and D. Shinar, "Imperfect in-vehicle collision avoidance warning systems can aid distracted drivers," Transp. Res. Part F Traffic Psychol. Behav., vol. 10, no. 4, pp. 345–357, 2007

[100] V. Saini, "Driver Drowsiness Detection System and Techniques : A Review," Int. J. Comput. Sci. Inf. Technol., vol. 5, no. 3, pp. 4245–4249, 2014.

[101] F. Guo, "Statistical methods for naturalistic driving studies," Annu. Rev. Stat. Its Appl., vol. 6, pp. 309–328, 2019

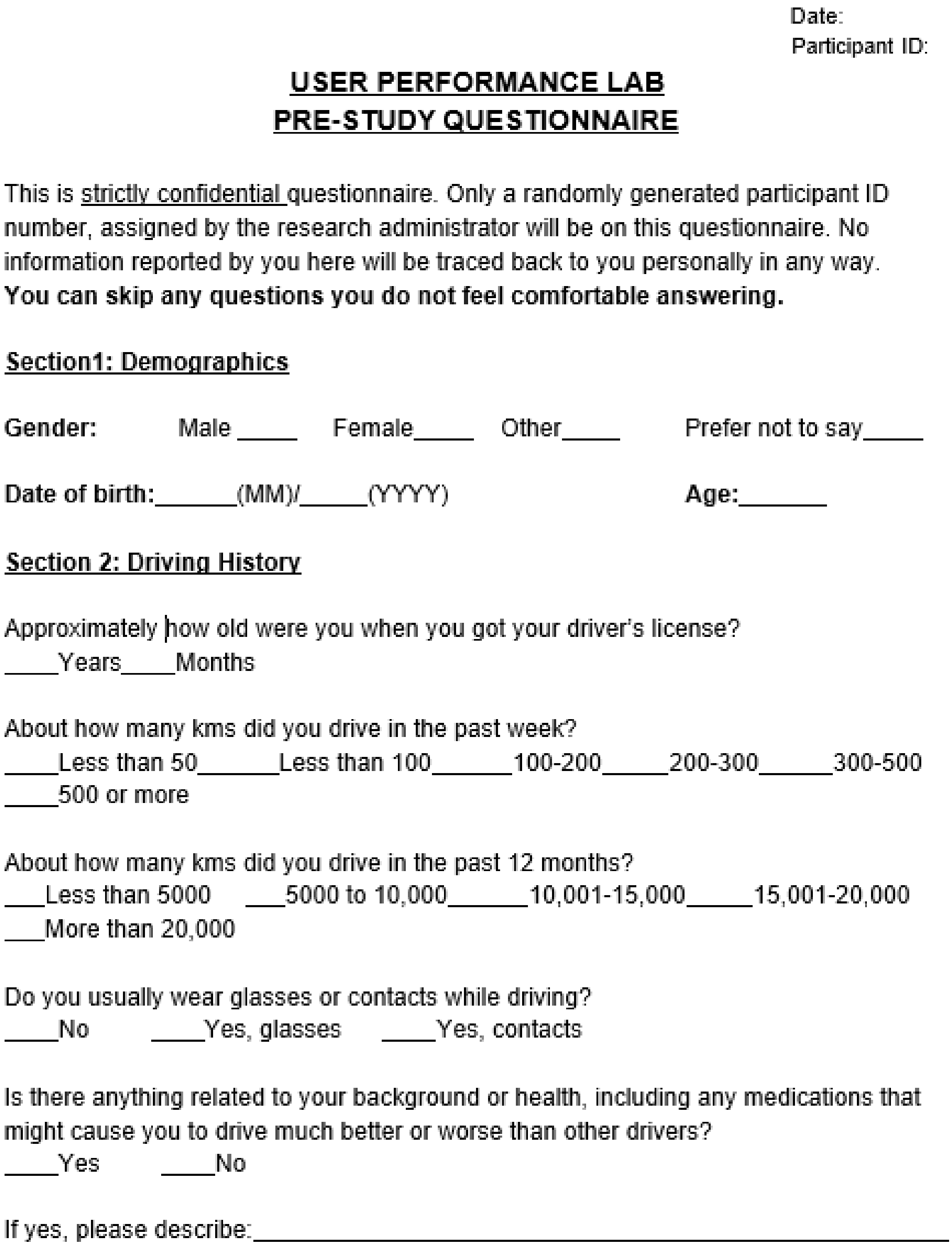
[102] Quintana, D., Guastella, A., Outhred, T., Hickie, I., & Kemp, A "Heart rate variability is associated with emotion recognition: Direct evidence for a relationship between the autonomic nervous system and social cognition", International Journal Of Psychophysiology, 86(2), 168-172, 2012.

[103] Hansen, A., Johnsen, B., & Thayer, J " Relationship between heart rate variability and cognitive function during threat of shock", Anxiety, Stress & Coping, 22(1), 77-89, 2009.

Appendix A

Questionnaires

The Questionnaires obtained from the participants before and after study are given below:



Date:
Participant ID:

USER PERFORMANCE LAB
PRE-STUDY QUESTIONNAIRE

This is strictly confidential questionnaire. Only a randomly generated participant ID number, assigned by the research administrator will be on this questionnaire. No information reported by you here will be traced back to you personally in any way. **You can skip any questions you do not feel comfortable answering.**

Section1: Demographics

Gender: Male _____ Female_____ Other_____ Prefer not to say_____

Date of birth:______(MM)/_____(YYYY) **Age:**_______

Section 2: Driving History

Approximately how old were you when you got your driver's license?
_____Years_____Months

About how many kms did you drive in the past week?
_____Less than 50______Less than 100______100-200_____200-300______300-500
_____500 or more

About how many kms did you drive in the past 12 months?
___Less than 5000 ___5000 to 10,000______10,001-15,000_____15,001-20,000
___More than 20,000

Do you usually wear glasses or contacts while driving?
_____No _____Yes, glasses _____Yes, contacts

Is there anything related to your background or health, including any medications that might cause you to drive much better or worse than other drivers?
_____Yes _____No

If yes, please describe:____

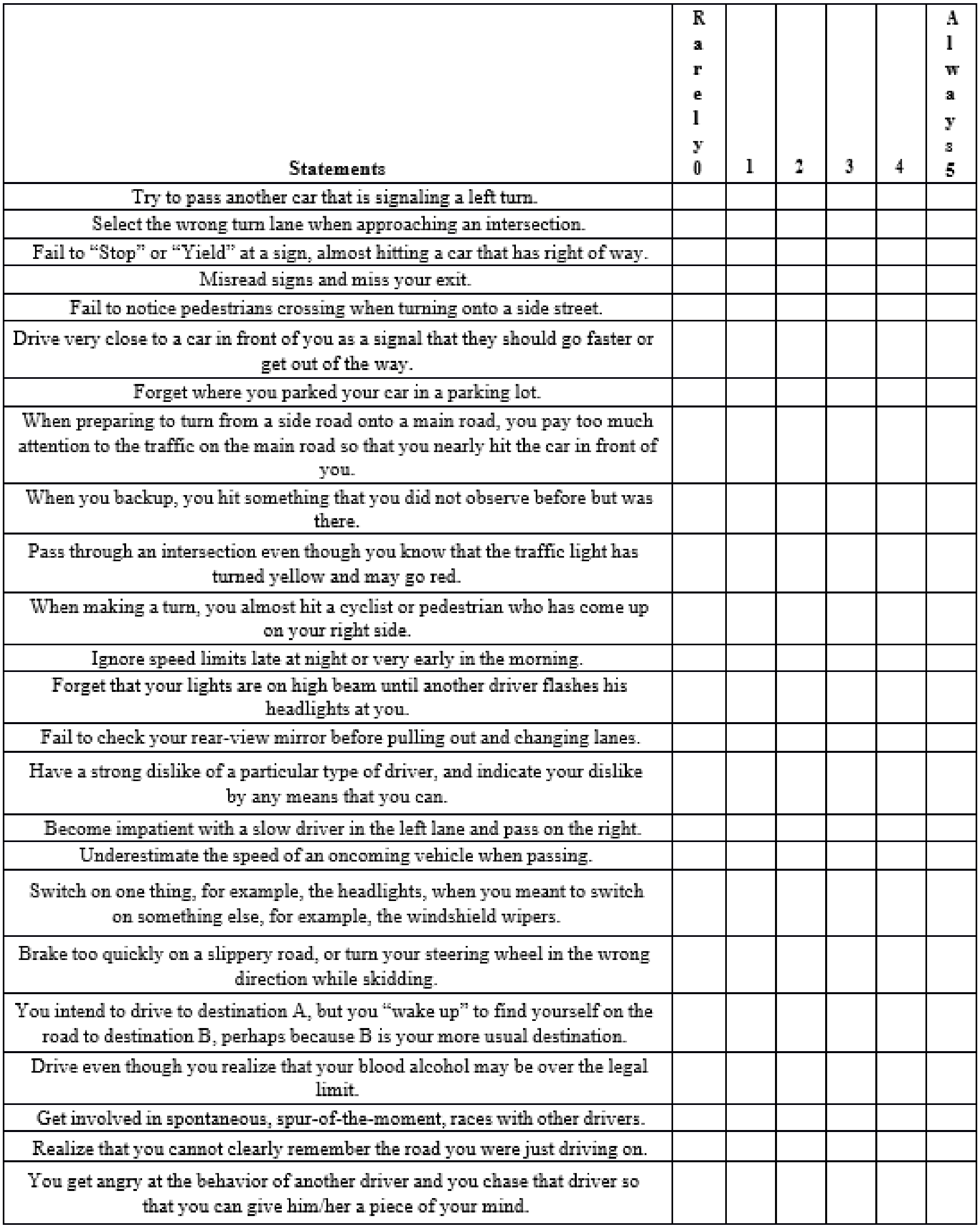
USER PERFORMANCE LAB
Driver Behavior Questionnaire

This is a ***strictly confidential*** questionnaire. Only a randomly generated participant ID number, assigned by the research administrator, will be on this questionnaire. No information reported by you here will be traced back to you personally in any way. **You can skip any questions you do not feel comfortable answering.**

Participant ID: **Date:**

There are 24 driving behavior statements and you are expected to rate them on a scale ranging **from 0 (rarely engage in this behavior) to 5 (engage in this behavior nearly all the time)** based on your own experience.

Please see the following page for the full questionnaire.



Statements	Rarely 0	1	2	3	4	Always 5
Try to pass another car that is signaling a left turn.						
Select the wrong turn lane when approaching an intersection.						
Fail to “Stop” or “Yield” at a sign, almost hitting a car that has right of way.						
Misread signs and miss your exit.						
Fail to notice pedestrians crossing when turning onto a side street.						
Drive very close to a car in front of you as a signal that they should go faster or get out of the way.						
Forget where you parked your car in a parking lot.						
When preparing to turn from a side road onto a main road, you pay too much attention to the traffic on the main road so that you nearly hit the car in front of you.						
When you backup, you hit something that you did not observe before but was there.						
Pass through an intersection even though you know that the traffic light has turned yellow and may go red.						
When making a turn, you almost hit a cyclist or pedestrian who has come up on your right side.						
Ignore speed limits late at night or very early in the morning.						
Forget that your lights are on high beam until another driver flashes his headlights at you.						
Fail to check your rear-view mirror before pulling out and changing lanes.						
Have a strong dislike of a particular type of driver, and indicate your dislike by any means that you can.						
Become impatient with a slow driver in the left lane and pass on the right.						
Underestimate the speed of an oncoming vehicle when passing.						
Switch on one thing, for example, the headlights, when you meant to switch on something else, for example, the windshield wipers.						
Brake too quickly on a slippery road, or turn your steering wheel in the wrong direction while skidding.						
You intend to drive to destination A, but you “wake up” to find yourself on the road to destination B, perhaps because B is your more usual destination.						
Drive even though you realize that your blood alcohol may be over the legal limit.						
Get involved in spontaneous, spur-of-the-moment, races with other drivers.						
Realize that you cannot clearly remember the road you were just driving on.						
You get angry at the behavior of another driver and you chase that driver so that you can give him/her a piece of your mind.						

Motion Sickness Susceptibility Questionnaire Short-form (MSSQ-Short)

1. Please State Your **Age**..............Years.   *2.* Please State Your Sex (tick box) **Male** [ ] 1   **Female** [ ] 2

This questionnaire is designed to find out how susceptible to motion sickness you are, and what sorts of motion are most effective in causing that sickness. Sickness here means feeling queasy or nauseated or actually vomiting.

Your CHILDHOOD Experience Only (before 12 years of age), for each of the following types of transport or entertainment please indicate:

3. **As a CHILD (before age 12)**, how often you **Felt Sick or Nauseated** (tick boxes):

	Not Applicable - Never Travelled	**Never Felt Sick**	**Rarely Felt Sick**	**Sometimes Felt Sick**	**Frequently Felt Sick**
Cars					
Buses or Coaches					
Trains					
Aircraft					
Small Boats					
Ships, e.g. Channel Ferries					
Swings in playgrounds					
Roundabouts in playgrounds					
Big Dippers, Funfair Rides					
	t	0	1	2	3

Your Experience over the LAST 10 YEARS (approximately), for each of the following types of transport or entertainment please indicate:

4. **Over the LAST 10 YEARS**, how often you **Felt Sick or Nauseated** (tick boxes):

	Not Applicable - Never Travelled	**Never Felt Sick**	**Rarely Felt Sick**	**Sometimes Felt Sick**	**Frequently Felt Sick**
Cars					
Buses or Coaches					
Trains					
Aircraft					
Small Boats					
Ships, e.g. Channel Ferries					
Swings in playgrounds					
Roundabouts in playgrounds					
Big Dippers, Funfair Rides					
	t	0	1	2	3

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High