Comparative Data Analysis of Older Driver's vs Younger Driver's Gap Acceptance Behavior at signalized left turns – A Driving Simulator Study

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

Drivers aged 65 and older are particularly prone to motor vehicle crashes, with approximately 20% of traffic fatalities occurring at intersections [11]. Intersections appear to be hazardous for drivers in this age group due to cognitive, perceptual, and psychomotor challenges. Older drivers find it particularly difficult to safely navigate left turns at signalized permissive intersections, having problems adequately detecting, perceiving, and accurately judging the safety of gaps. The increase in the number of elderly drivers has been paralleled by an increase in road-related accidents due to age-related fragility. By 2030, more than 21% of the adult population is projected to be over 65 years old [1]. However, previous studies have not adequately considered the combined effects of the randomized gap, queue length, traffic volume, pedestrians, and physiological factors on driving.

The current study aims to address the gap in the literature by explicitly examining older and younger drivers' gap acceptance behaviors during permissive left turns at four-way intersections. The main objective of this thesis is to study, identify and analyze the effect of Gap Acceptance Behavior on age, traffic volume, queue length, and physiological factors such as heart rate variability (HRV), electrodermal activity (EDA), and motion sickness among older and younger drivers. The data was collected from a driving simulator study comprising 40 participants aged between 20-30 for younger and 65 years for older. The collected data was used for comparative analysis, with the Gap Accepted by the drivers calculated from the video data. The gap is calculated as the distance between the left turning vehicle and the oncoming traffic. All recruited drivers were healthy.

Each participant navigated twelve scenarios, six with lower traffic conditions and six with higher traffic conditions. Each lower and higher traffic scenario varied in queue length, with the number of cars in front of the ego vehicle varying from 0, 1, and 2. All varying queue lengths also had one with a pedestrian and another without. The physiological data collected through the Empatica4 wristband was also considered to study the gap acceptance behavior. Another parameter, motion sickness susceptibility score (MSSQ), was obtained from a questionnaire the participants completed after the experiment. Of these factors, queue length, traffic volume, and pedestrians play a significant role in studying gap acceptance. There is a significant difference in

accepting and rejecting the gap between young and older drivers. Older drivers' decision is affected more by factors, such as traffic volume, age, queue length, HRV, EDA, MSSQ score and the presence of pedestrians.

This study showed that older drivers exhibited longer gap acceptance times than their younger counterparts while turning left across traffic at permissive intersections. Researchers may use the findings to better understand gap acceptance behaviors, while policymakers may utilize the results to design mobility guidelines.

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List of Abbreviations

- EDA – Electrodermal Activity
- HRV – Heart Rate Variability
- FHWA - Federal Highway Administration
- DT- Decision Tress
- RD – Random Forest
- KNN – K-nearest neighbor
- IB – Instance Based
- GSR - Galvanic Skin Response
- MSSQ – Motion Sickness Susceptibility Questionnaire
- SSQ – Simulator Scoring Questionnaire
- DF - Degrees of Freedom
- WRAP - Waterloo Research in Aging Participant Pool
- TMT- Trail Making Test
- UTC - Unix time stamp
- BPM - Beats Per Minute
- MSSQ – Motion Sickness Susceptibility Score

Chapter 1
Introduction

1.1 Motivation

There is a growing concern regarding the safety of drivers on the road, particularly when it comes to more complex maneuvers such as left turns. Several factors such as age, queue length, traffic volume, and pedestrian crossing can affect the drivers in choosing the safe gap while taking left turns in four-way intersections. While these factors have been researched separately, they have not been combined into a single study to enable the examination of interaction effects which is the purpose of this research. Figure 1.1 shows the performance differences in fatal crashes at the intersections among different groups of drivers [4].

Approximately 20% of traffic fatalities occur at intersections, and one-third of these fatalities occur at signalized intersections. Left-turn collisions account for about half of the fatalities at signalized intersections [11]. Left-turn lanes are used to provide a safe location for left-turning vehicles to wait for a gap in traffic to turn left and are used to reduce rear-end collisions. Older drivers have problems adequately detecting, perceiving, and accurately judging the safety of a gap. They tend to underestimate the speed of approaching vehicles and ignore other hazards. By 2030, the older adult population is projected to increase disproportionately and more than 21% will be above 65 years [1]. It is expected that in Canada by 2026 that 1 out of 5 drivers will be 65 years or older [2]. Studies have shown that older drivers are more likely to be involved in accidents at intersections. Left turns can be particularly challenging for this demographic due to declining vision, cognitive abilities, and reaction time [3]. It is predicted that a large proportion of both women and men will continue to drive in their 80s [3]. On the other hand, young male drivers, tend to involve in a crash at intersections due to insufficient experience, over speed and, aggressive driving [5]. The annual number of fatalities accounts for an average of 112 dead individuals per day in vehicle crashes caused by younger drivers and the annual number of fatalities tend to increase since 2007 these vehicle crashes are the leading reason for the death of people aged below 34 [6].

Accurately finding the safe time interval to accept the gap in a four-way intersection is more complicated when compared to the T-Junctions. However, more research is needed to determine how the gap acceptance rate of younger and older adults is affected by various factors while taking left turns at four-way intersections. One of the factors affecting the gap acceptance rate is traffic flow [7], when there is high traffic flow the signal wait time is more a hurry the drivers tend to take an unsafe at the intersection. In addition to this, queue length [8] i.e., the number of cars in front waiting to take a left turn will also affect the decision regarding the gap made by the drivers. Queue length tends to impact more due to time pressure created by the drivers [8][9].

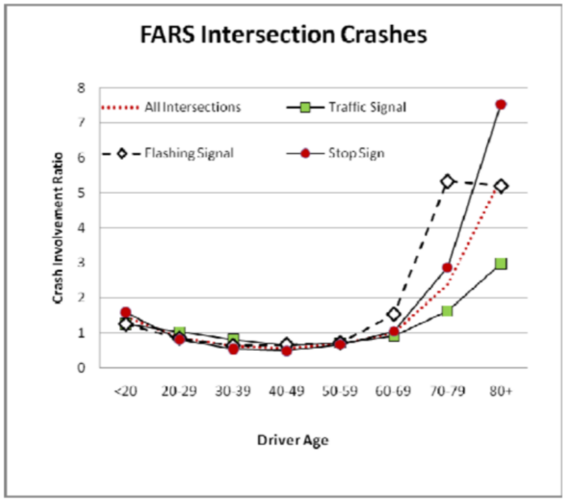


Figure 1.1 Crash Involvement Ratio (CIR) for Fatal Analysis Reporting System (FARS) intersection crashes by traffic control device and driver age [4]

Any distractions like pedestrians crossing the road [10] will also have an impact on the gap acceptance rate as the focus will change and the drivers will deviate while taking left turns. Therefore, it is important to understand how these factors can impact older and younger drivers' gap acceptance behavior in four-way intersections.

1.2 Research Objective

Young and elderly drivers have a high crash rate while taking left turns at intersections. Drivers aged 65 and older are prone to age-related issues like cognitive, psychomotor challenges and perceptual that might have negative impair on their driving performance. On the other hand, young drivers have a greater tendency to adopt a risky driving style and many behaviors associated with poor road safety. Moreover, these drivers can experience difficulties in certain driving situations like higher levels of traffic, more queue length, and pedestrians crossing the road.

The following research objectives aim to examine the effect of gap acceptance behavior in different age groups and are the focus of this thesis:

1. Differences in the gap acceptance rate across young (20-30 years) and senior adults (above 65 years).
2. The effect of gap acceptance behavior on different types of queue length and varying traffic volume.
3. The influence of pedestrians on the gap acceptance rate.
4. The effect of gap acceptance behavior on EDA, HRV, and MSSQ scores.

1.3 Thesis Organization

The remainder of this thesis is structured as follows:

1. Chapter 2 provides a background of this thesis, literature regarding left turn gap acceptance behavior, consideration of young and old drivers, and physiological factors in the gap acceptance. The gap in the literature is also discussed.
2. Chapter 3 discusses the data collection methods and material for the experiment, hypothesis, and participant questionnaires.
3. Chapter 4, an exploration into the data, synchronizing, and visualizing them are elaborated and discussed. This chapter also discusses the observation and insights obtained.
4. Chapter 5 discusses the results of the study and shows the results of the statistical analysis.
5. Chapter 6, Conclusion, gives a summary of the study, its limitations, and its future work.

Chapter 2

Background

2.1 Review of the Literature

2.1.1 Gap Acceptance Behavior and Left Turns

A four-way stop-controlled intersection is a type of intersection where traffic is controlled by stop signs located in all four directions. At these intersections, all vehicles are required to come to a complete stop at the designated stop line or before entering the intersection and yield the right of way to any other vehicles that have already arrived at the intersection [101].

The rules for right-of-way at four-way stops are typical as follows:

- The first vehicle to arrive at the intersection and come to a complete stop has the right of way to proceed through the intersection first.
- If two or more vehicles arrive at the intersection at the same time, the vehicle on the right has the right of way [101].
- Vehicles that are turning left must yield to any oncoming traffic that is continuing straight through the intersection or turning right.
- If two vehicles are facing each other and both want to turn left, they must yield to each other and the vehicle that arrived first has the right of way.

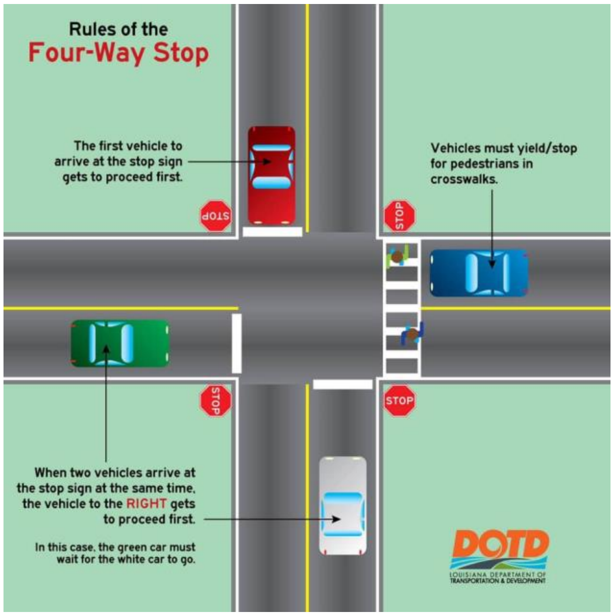


Figure 2.1 Rules of Four-way Stop [101]

A two-way stop-controlled intersection is a type of intersection where two roads or streets meet, and traffic on one of the roads or streets is required to stop and yield the right-of-way to traffic on the other road or street. At a two-way stop-controlled intersection, there are stop signs on two sides of the intersection, typically facing the road with lower traffic volume or the road without a through connection [107]. When approaching a 2-way stop intersection and intending to make a left turn, the driver should come to a complete stop and yield to any vehicles and pedestrians approaching from the opposite direction. If there is no oncoming traffic or pedestrians, the driver may proceed with the left turn. However, if there is oncoming traffic or pedestrians, the driver must wait until it is safe to make the turn [106]. The driver should carefully assess the speed and distance of the oncoming traffic, and only turn when there is a sufficient gap in traffic to complete the turn safely [104-107]. Left turns at 2-way stop-controlled intersections can be challenging and require the driver to remain alert and focused. Drivers must also be prepared to yield to any emergency vehicles or vehicles making a U-turn at the intersection.

At a T-junction, left turns are made from one road onto another road that intersects it perpendicularly. The rules for making a left turn at a T-junction depend on whether the junction is controlled by traffic signals or is an uncontrolled intersection. At an uncontrolled T-junction, drivers must yield the right-of-way to any vehicles on the perpendicular road [100]. The driver should stop behind the stop line or yield sign and check for oncoming traffic and pedestrians before making the left turn. If the T-junction is controlled by traffic signals, drivers must follow the left turn signal or arrow when it is safe to do so. The traffic signal may include a dedicated left turn lane, and drivers must stay within this lane while making their turn [105-107]. Drivers should be aware of any pedestrians or bicycles in the area and yield to them as necessary. In some cases, a T-junction may also have a roundabout or a mini roundabout. When making a left turn at a roundabout or mini-roundabout, drivers must follow the roundabout rules and yield to any vehicles in the roundabout before entering it.

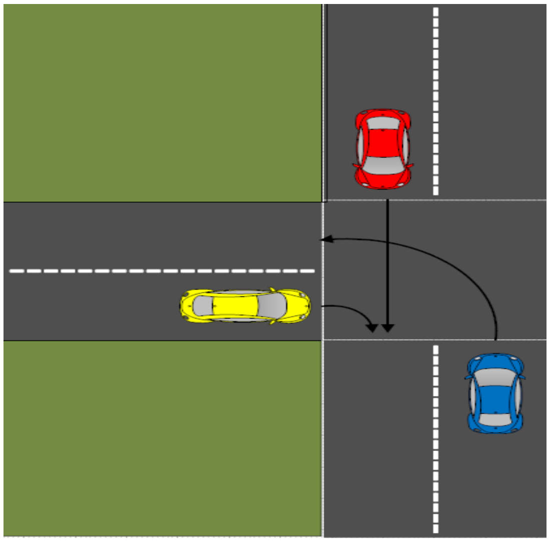


Figure 2.2 Left Turn at T-Junction [100]

Protected left turns refers to left turns that are allowed with the aid of a dedicated left turn signal or arrow. A protected left turn signal provides a green arrow to indicate that it is safe for left-turning vehicles to proceed without having to yield to oncoming traffic. Protected left turns to provide a higher level of safety and predictability for left-turning drivers, as they do not have to judge the speed and distance of oncoming traffic or compete for a gap in traffic. This can also reduce congestion and improve traffic flow, as left-turning vehicles can proceed more efficiently without having to wait for a gap in oncoming traffic.

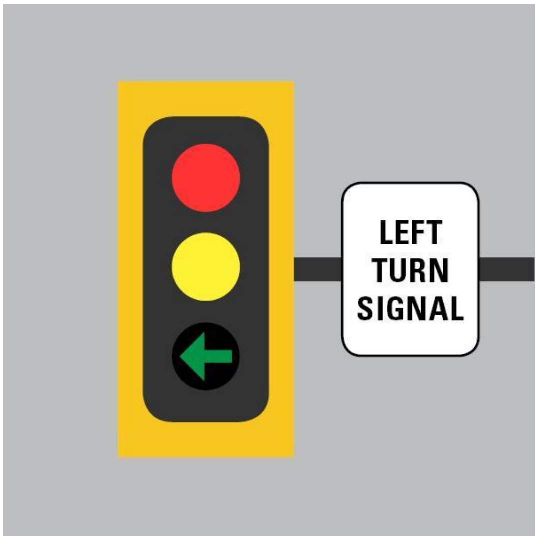


Figure 2.3 Protected Left Turn Signal [102]

Permissive left turns to refer to left turns that are allowed without a dedicated left turn signal or arrow. Instead, drivers are permitted to turn left when it is safe to do so, typically when there is a gap in oncoming traffic [104]. In a permissive left turn situation, drivers must yield to oncoming traffic and pedestrians and ensure that they have enough time to complete the turn safely.

Permissive left turns to require drivers to use their judgment and make quick decisions based on the speed and distance of oncoming traffic. They can be challenging for inexperienced or nervous drivers, who may hesitate to make the turn or misjudge the speed of oncoming traffic. Drivers must remain alert and focused when making permissive left turns and be prepared to stop or yield if necessary. In this study, only permissive left turns are considered [103].

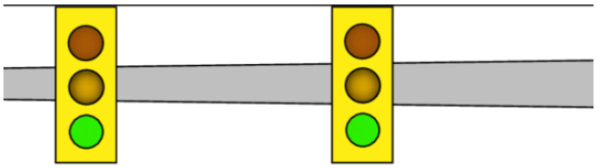


Figure 2.4 Permissive Left Turn Signal [103]

Gap acceptance behavior in left turns is a crucial aspect of safe and efficient driving. When making a left turn, drivers must wait for an appropriate gap in oncoming traffic before proceeding. The driver's decision to accept a gap in oncoming traffic is based on a variety of factors, such as the size and speed of the oncoming vehicles, the distance of the gap, the driver's reaction, the driver’s age, the number of oncoming vehicles, presence of pedestrians and the number of car’s waiting to make a left turn.

In left turns gap acceptance behavior can be particularly challenging due to the need to cross one or more lanes of oncoming traffic [11,15,106]. Drivers must carefully assess the speed and distance of oncoming traffic in each lane and select an appropriate gap in which to turn. This requires the driver to make quick and accurate judgments based on a combination of visual cues and their own driving experience.

Drivers who are uncertain about their gap acceptance behavior should be more cautious when making left turns, resulting in longer wait times and potential traffic delays. Conversely, overconfident drivers may take risks and attempt to turn into gaps that are too small or too fast, increasing the risk of a collision. Drivers need to practice techniques and remain vigilant when making left turns.

When making a permissive left turn, drivers will typically use the following gap acceptance behavior:

- Perception: The first step is for the driver to perceive the oncoming traffic and determine whether there is a gap that is large enough to safely make the turn. This includes assessing the speed and distance of the oncoming vehicles, as well as any other potential hazards, such as pedestrians or cyclists.
- Decision: Once the driver perceives a potential gap, they must decide whether it is safe to make the left turn. This decision will be based on factors such as the size of the gap, the speed of the oncoming traffic, and the driver's confidence in their ability to complete the turn safely.
- Action: If the driver determines that it is safe to make the turn, they will initiate the turn and proceed across the oncoming traffic. If they decide that it is not safe, they will wait for the next potential gap and repeat the process.
- Adaptation: Throughout the process of making a permissive left turn, drivers may need to adapt their behavior based on changing conditions. For example, if a driver perceives a potential gap but then realizes that it is too small, they may need to abort the turn and wait for a larger gap.

2.1.2 Gap Acceptance Behavior at Four-way Intersections

Gap acceptance is an important aspect of traffic flow and safety, as it directly affects how vehicles merge into traffic and navigate through intersections. Gap acceptance behavior is a critical factor in left turns, and it is influenced by a range of factors, including driver characteristics and traffic conditions. Gap acceptance behavior in left turns refers to the decision-making process used by drivers to determine whether it is safe to turn left across oncoming traffic. When making a left turn, drivers must judge the speed and distance of oncoming traffic and determine whether there is a sufficient gap in traffic to safely complete the turn.

According to Federal Highway Administration (FHWA) [23] the subject driver must follow five sub-tasks (Approach, Deceleration, Intersection Entry, prepare for the turn, and Execute turn) as shown in Figure 2.5 to accept a safe gap while making a left turn at the four-way intersections. The characteristics of these five sub-tasks are listed in Table 2.1.

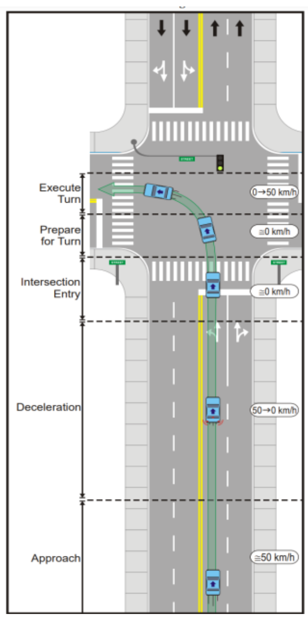


Figure 2.5 Sub-Tasks for Left turn at four-way intersection [23]

Nearly 76 percent [23] of crashes tend to occur at the prepare-at-turn phase. Age can be one of the important factors in left-turn gap acceptance behavior, with older drivers generally requiring longer gaps before attempting a left turn. Many Older people aged 65 and above are dependent on vehicle use for the rest of life and there is a need to retain their ability to drive safely with continued driving and mobility [12]. New State Farm [15] reported that more than one-quarter of Canadians want to hold driver's licenses past 85 years of age. Safe Transportation is important for older adults to maintain their health, well-being, and quality of life [16][17]. For instance, in rural areas driving is very important as the travel distances are large and there are fewer modes of transport than driving, senior adults need transportation to access hospitals [30].

Table 2.1Characteristics of the sub-tasks for left-turn at four-way intersections.

Sub-Tasks	Driving Objectives
Approach	Identifying the upcoming traffic at the intersection.
Deceleration	Lowering the speed and stopping at the intersection.
Intersection Entry	Look for the correct entry position.
Prepare for Turn	Wait for the safe gap in the traffic.
Execute Turn	Complete the turn.

Additionally, older drivers who have discontinued driving rely on their family and friends for medical and other needs which might eventually become inconvenient for the caretakers [31]. However, most of the older drivers tend to avoid a few driving scenarios that they feel are difficult and drive less in general. They tend to avoid high-traffic road conditions, left turns in busier junctions, they also avoid poor weather conditions, and night-time driving even if they are safe drivers [32-34]. Similar findings were obtained in another study where older drivers particularly avoided left turns or took unsafe gaps while turning left at the four-way intersections which were reported in crashes [35]. Hence, it is important to reduce crash-related deaths as the population of older adults increases. Many studies listed factors due to which older adults are more likely to be involved in intersection collisions. They are as follows:

- Slower response time [37].

- Older drivers are very prone to a dilemma when they are closer to an intersection, whether to stop at a fa or yellow light or make a turn [38].
- Lower visual acuity makes it harder to see traffic signals, pedestrians, or other vehicles [37,39].
- Poor gap selection [25-29].
- Greater difficulty to handle complex driving situations such as traffic and interactions with other road users. [7-9,35].
- Underestimating the speed of other vehicles [40,41].

According to Chovan et al. [24] there was a list of possible collision-causing errors at the four-way intersections when drivers tend to take a left turn. Table 2.2 shows the possible errors made by the drivers.

Table 2.2 Sources of driver errors when taking left turns ate four-way intersections [24]

Driver Task	Possible Errors
Approach the intersection	Driver might be unaware of the intersection ahead and its geometry.
Signal	Driver might not signal to other traffic.
Decelerate	Driver might not decelerate sufficiently to process intersection information properly.
Perceive traffic control device	Driver might be unaware of traffic control device altogether or might be unaware of signal characteristics.
Heed traffic control device	Driver might not perceive correct device characteristics.
Perceive color of traffic light	Driver might be unaware of the status (flashing versus solid) or color (red, amber, green) of a light.
Respond appropriately to color of light	Driver might exhibit incorrect behavior to a particular light characteristic.
Observe other traffic	Driver might be unaware of other traffic (crossing or oncoming).
Judge gap in oncoming traffic	Driver might misjudge the gap in or velocity of oncoming traffic.
Judge gap in cross traffic	Driver might misjudge the distance of the gap in traffic or the velocity of oncoming traffic if he or she is distracted by cross traffic.
Edge out into traffic to confirm clearance when the driver's vision is obstructed	Driver might not realize that vision is obstructed or might edge out into traffic without confirming information.
Check the pathway	Driver might not check the pathway or might misperceive objects (vehicles or pedestrians) in the pathway. Driver might not anticipate other traffic behavior properly.
Adjust velocity to turn	Driver might turn too fast or too slow.
Complete the left turn	Driver might stop before the turn is completed.

Older drivers tend to accept longer wait times than younger drivers, whereas younger drivers display more aggressive gap acceptance than older adults [23]. When considering all age groups, young people have the highest rates of traffic death and injury per capita per kilometer driven [48]. Crash statistics on Canadians show that young drivers represent only 13% of the licensed driving population, they account for approximately 20% of motor vehicle deaths and injuries [49]. They tend to speed up in lower-traffic areas where they have a greater opportunity to speed up.

Young drivers were found to receive more tickets for driving over the speed limit than older drivers and lost control of their vehicles. Furthermore, younger drivers accepted narrower gaps in traffic when making left turns. Motor vehicle crashes continue to be the leading cause of death among the younger population, typically between the ages of 18 to 30 years. A study of vehicle crashes [49] in Canada from 1990 to 2012 stated that persons aged 16 to 25 contributed to 13.6% of the population but they also contributed to 27.2% of all motorcyclist fatalities. The most common types of young-age driver crash involve left-hand turns, rear-end events, and running off the road [48].

When a young driver is carrying a passenger, the risk of a fatal car crash doubles. If more co-passengers are present, the odds are five times as likely [47]. The presence of peer passengers also had a significant influence on aggressive gap acceptance in young drivers [42-45]. A study conducted to examine such conditions confirms that an increase in younger co-passengers tends to increase the risk of driving among drivers aged 18-30 years [46]. In all this research mostly the gap intervals were fixed at certain intervals and the drivers were forced to accept the gap at these intervals. From the literature reviews of [24-29], it is evident that most of the research fixed the gap intervals ranging from 2s to 6s. These studies on young drivers and older drivers give us more reasons why they are of great interest when considering the gap acceptance behavior at left turns in four-way intersections.

2.1.3 Factors and ways to detect the accepted gap

In left turns, as drivers do not have the right of way, a driver's task is generally to assess and choose an appropriate gap. A driver approaching the intersection must analyze whether this gap in the traffic is large enough to safely make a turn or not. A driver generally tends to accept the safer gap and rejects the rest of the gap. The estimation of critical gaps accepted by the drivers is the most difficult task to be observed with traffic volumes [26]. There are more than 20-30 methods to observe the accepted gap and all these methods provide different solutions [26].

The gap is not a constant but varies from driver to driver and from time to time. Gap was found to also vary with subject traffic volume, queue length, age, weather conditions, etc. [26-28] The Literature review from [26,50] concludes that one of the convenient and easier methods to detect gaps is the car turning time. In this method, the gap is the distance between the left turning vehicle and the oncoming traffic. Similarly, there are so many studies that use various algorithms like Decision trees (DT), Random Forest (RD), K-nearest neighbor (KNN), instance based (IB) [51] methods to study the gap acceptance behavior in the drivers. The density of the traffic and queue length also plays a vital role when considering the gap in accepted time. More crashes tend to occur in higher-traffic areas when compared to lower-traffic areas [58] [60-61]. As the queue length at the intersection increases, i.e., the number of vehicles in front of the subject car, the wait time at the intersection increases which might cause panic and lead to unsafe gap acceptance.

While discussing the physiological factors considered in the study of gap acceptance factors like electrodermal Activity (EDA) and heart rate variability (HRV) [52,95] are commonly taken into consideration. EDA, also known as Galvanic Skin Response (GSR), is an electrical change that occurs in the skin. The measurement is taken usually from the palm or the sole [53] [56-57].

Most of the studies conducted using driving simulators usually include Motion Sickness as an important factor. The study of motion sickness uses the Motion Sickness Susceptibility Questionnaire (MSSQ), which records individual exposure to motions in different transportation systems like cars, buses, trains, etc., and their corresponding level of occurrence of illness in these transportations [54]. The susceptibility of motion sickness is usually collected through 11 questionnaires. These responses are being used for several motion and motion sickness-related studies. Similarly, for the studies conducted in a simulator environment, the Simulator Sickness Questionnaire (SSQ) can be used to determine whether the participant has simulator sickness or not [55].

2.2 Gap in Literature

To summarize, there has been insufficient research conducted on gap acceptance behavior for different age groups, considering traffic volume, queue length, pedestrian crossings, and psychological factors altogether. Since younger and older drivers tend to have higher crash rates at intersections compared to other places, they could benefit from this study, which might help avoid collisions caused by younger drivers' poor driving style and aggressiveness and older drivers who experience age-related declines in their driving.

Several studies have been conducted on left-turn gap acceptance behavior at permissive four-way intersections, as discussed in the literature review. Most studies used vehicle parameters such as acceleration, braking force, fixed gap intervals, dilemma zone, and traffic density to detect the gap accepted by drivers. However, not much research has been done analyzing the effect of gaps taken by the drivers while considering factors such as randomized gap lengths, fixed traffic volume, fixed queue length, and physiological factors specifically HRV and EDA in a single study.

As discussed in section 2.1.1, both younger and senior drivers find it difficult to make left turns at four-way signalized intersections by accepting a safer gap. Hence, this thesis attempts to fill the gap in the literature by combining all the major factors that impact drivers when choosing a safe gap to make a safe left turn at four-way signalized intersections.

The next chapter details the methodology for data collection, the materials used, and the experiment's design. Additionally, it explains the technicalities of the equipment used.

Chapter 3

Human Experiments

3.1 Hypothesis and Study Overview

When making a left turn, the accepted gap value is the minimum amount of time required for a vehicle to make the turn safely without causing a collision with other vehicles.

A queue refers to a line of vehicles waiting to enter an intersection or merge into traffic. When the queue length is long, it can cause drivers to behave differently than when the queue length is short.

The traffic volume can also affect the actual size of the gap that drivers accept. In general, drivers tend to accept smaller gaps when the traffic volume is low and larger gaps when the traffic volume is high. This is because a larger gap is more likely to occur when there are more vehicles on the road, giving drivers more time to make a safe turn or merge.

When there is high traffic volume, drivers may be more cautious and wait for a longer gap before entering an intersection or merging into traffic. This is because there are more vehicles on the road, which increases the risk of collisions. On the other hand, when there is low traffic volume, drivers may be more likely to take risks and accept smaller gaps, as they feel there is less danger of collision.

This study aimed to examine age (young versus old-aged drivers) differences in left-turn gap acceptance rate on different traffic volumes (high versus low), pedestrians (with pedestrians versus without pedestrians), and queue lengths (one versus two versus three).

When considering the age of the drivers for the accepted gap,

> *Null Hypothesis*, H_0: there is no change in the gap in accepted values between young and old age drivers.
>
> *Alternative Hypothesis*, H_A: there is a change in the gain p accepted values between young and old age drivers.

When queue length is considered,

> H_0: There is no significant difference in the mean accepted gap value between different queue lengths.

H_A: There is a significant difference in the mean accepted gap value between different queue lengths.

When traffic volume is considered the null and alternative hypothesis is as follows,

H_0: There is no significant difference in the mean accepted gap value between different traffic volumes.

H_A: There is a significant difference in the mean accepted gap value between different traffic volumes.

When pedestrians are considered, the hypothesis is that,

H_0: There is no significant difference in the mean accepted gap value between the presence of pedestrians.

H_A: There is a significant difference in the mean accepted gap value between the presence of pedestrians.

When considering the age of the drivers for the rejected gap,

Null Hypothesis, ***H_0***: there is no change in the gap rejected values between young and old age drivers.

Alternative Hypothesis, ***H_A***: there is a change in the gap rejected values between young and old age drivers.

When queue length is considered,

H_0: There is no significant difference in the mean rejected gap value between different queue lengths.

H_A: There is a significant difference in the mean rejected gap value between different queue lengths.

When traffic volume is considered the null and alternative hypothesis is as follows,

H_0: There is no significant difference in the mean rejected gap value between different traffic volumes.

H_A: There is a significant difference in the mean rejected gap value between different traffic volumes.

When pedestrians are considered, the hypothesis is that,

H_0: There is no significant difference in the mean rejected gap value between the presence of pedestrians.

H_A: There is a significant difference in the mean rejected gap value between the presence of pedestrians.

When considering the values of EDA,

H_0: There is no significant difference in the EDA value between the gap accepted rates of the drivers.

H_A: There is a significant difference in the EDA value between the gap accepted rates of the drivers.

When considering the values of HRV,

H_0: There is no significant difference in the HRV value between the gap accepted rates of the drivers.

H_A: There is a significant difference in the HRV value between the gap accepted rates of the drivers.

When considering the baseline values of EDA,

H_0: There is no significant difference in the EDA values between baseline and distracted.

H_A: There is a significant difference in the EDA values between baseline and distracted.

When considering the baseline values of HRV,

H_0: There is no significant difference in the HRV values between baseline and distracted.

H_A: There is a significant difference in the HRV values between baseline and distracted.

When MSSQ is considered, the hypothesis is that,

H_0: There is no significant difference in the MSSQ score between the gap accepted rates of the drivers.

H_A: There is a significant difference in the MSSQ score between the gap accepted rates of the drivers.

When considering the young and older driver's queue length, traffic volume, and presence of pedestrians for the accepted gap, the hypothesis is stated as,

> ***H_0***: There is no change in younger and older drivers' accepted gap values between varying queue length, traffic volume, and presence of pedestrians.
>
> ***H_A***: There is a change in younger and older drivers' accepted gap values between varying queue length, traffic volume, and presence of pedestrians.

The value of the accepted gap is obtained from the driving simulator, physiological factors are obtained through sensors in wristbands worn by the participants. The MSSQ scores are obtained through questionnaires.

3.2 Methods and Materials

3.2.1 Participants

This study consisted of 40 participants recruited through flyers and emails sent to the Research Institute of Aging, Waterloo Research in Aging Participant Pool (WRAP), and various departments at the University of Waterloo. To participate in this study participants must be between the ages of 20-30 (young) or older than 65 years. They will be required to possess a valid Canadian G2 or G Driver's License and be active drivers at the time they participate in the experiment. The sample comprised 20 young (20-30 years; Mean= 25.95) and 20 old-aged drivers (above 65 years; Mean= 77.95). The young participants had between 1 to 11 years of driving since obtaining their first driver's license with an average of 5.9 years, while the old-aged participants had between 49 to 79 years of driving with a mean of 60.5 years.

They were screened using the cut-off score of 29 seconds or greater for test A and 75 seconds or more for test B on the Trail Making Test (TMT) (attached in appendix A) [67] and a cut-off score of 23 on the MSSQ-Short [66]. Those who had a visual acuity poorer than 20/50 in Snellen Near and Far Visual Acuity tests [65][69] with or without the aid of corrective lenses were excluded from the study. The individuals with known vertigo or motion sickness were not eligible to participate as they are prone to develop simulator sickness.

Table 3.1 Analyzed sample demographics

Demographic	Young (n = 20)	Old (n = 20)
Age (years)		
Minimum-Maximum	20-30 years	Above 65 years
Mean	25.95	77.95
Standard Deviation	1.66102	5.7954
Driving experience (years)		
Minimum-Maximum	1-11	49-79
Mean	5.9	60.5
Standard Deviation	3.08	7.5674
MSSQ		
Minimum-Maximum	0-18	0-21
Mean	2.8	2.4
Standard Deviation	4.6508	5.364

The young-aged drivers aged 20-30 years were used as the control group to compare with the older group aged above 60 years. The young drivers were mostly students from the University of Waterloo as well as the neighboring colleges.

The young-aged participants had a mean MSSQ score of 2.8 (SD=5.36) while the older participants had a mean score of 2.4 (SD=4.65). The scores of the young-aged ranged from 0 to 18 whereas, for the older group, it ranged from 0 to 21. Unfortunately, 3 old-aged participants dropped out after experiencing motion sickness during the practice trials. No young drivers reported motion sickness at the end of the experiment.

The study took around 60 mins on average and was remunerated $15. This study was granted ethics clearance (ORE # 44672) through the University of Waterloo Office of Research Ethics and was conducted as stated in the approved protocols.

3.2.2 Procedure

If a participant chooses to participate, they must sign the consent form. After this, they will be asked to fill in a Motion Sickness Susceptibility Questionnaire (MSSQ), included in Appendix A, based on which they might be requested to discontinue the study to avoid simulator-based sickness and will be remunerated for the time spent based on the scoring obtained in the MSSQ questionnaire. Once the participant has qualified (score below 23) for the simulator sickness scoring, they will be asked to fill in demographic details and TMT which assesses their response time in two parts (part a cut-off score is 29 seconds and part b cut-off score is 75 seconds).

Before starting the experiment, participants must drive a car simulator through a sample scenario consisting of a suburban road with no traffic, to establish competence in handling the equipment. All this while they will be wearing the physiological sensor to collect baseline data. After the training, the participant wears the eye tracker, which must be calibrated along with the physiological sensor. The experimental flow is shown in Figure 3.1.

Participants must drive through twelve road scenarios consisting of different traffic volumes, and queue lengths elaborated upon in the following sections. Each of these scenarios is approximate of equal length; speed and other vehicle variables are observed throughout these scenarios. As a part of the post-questionnaire, they completed the Simulator Sickness Questionnaire [69] (see Appendix A) to measure simulator sickness and completed the driving style questionnaire (see Appendix A) to measure the aggressiveness of the drivers. Finally, the participants were thanked for their participation and remunerated accordingly.

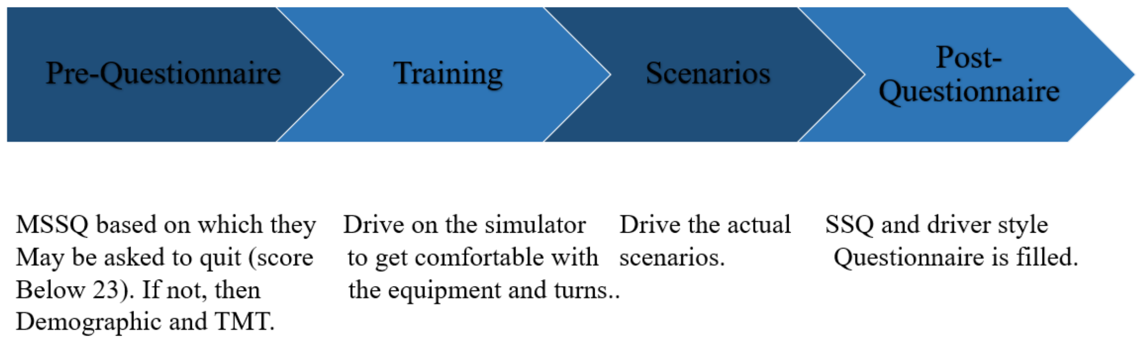


Figure 3.1 Experimental flow for each participant

3.2.3 Apparatus

In this study, data to evaluate driver behavior was observed from multiple modalities such as physiological, eye-tracking, and vehicle kinematics. The drive consisted of following directions from the audio and making left turns as per the directions. The vehicle was reset to the previous path if they missed a turn in the navigation and could resume driving from the starting position.

There was the presence of only the experimenter other than the participant inside the room while the experiment was going on. The participants were made aware that they can ask to stop the experiment at any point in time, depending on their comfort level with the equipment and experiment.

The following equipment was used for this study:

1. Carla Driving Simulator: Carla is an open-source driving simulator that allows users to create and integrate custom scenarios and maps. It also supports sensors such as lidar, radar, and camera. This also supports different kinds of road conditions such as urban, suburban, and highway. The setup for the simulator is shown in Figure 3.2.

Figure 3.2 Simulator setup – includes the Logitech G29 steering wheel and pedal set.

2. Dikablis Glasses 3: The eye-tracker is a glass with an integrated camera as shown in Figure 3.3 that will record the video of the user's eye and surroundings with a resolution of 768*576 px at a frequency of 30 HZ. This needs 4-point calibration to track the pupil of the eye.

Figure 3.3 Ergoneers Dikablis Glasses 3 Eye Tracker used in the experiment [70]

3. E4 Empatica wristband: It is a physiological monitoring band that collects data on EDA (Electrodermal activity) at 4Hz, HR (Heart Rate) at 1Hz, the temperature a,4Hz, and IBI (Inter-Beat interval). The initial time of the session is represented in the Unix time stamp (UTC). The band can be connected to any device with a Bluetooth connection and transfer data in real time. The band and its sensors are shown in Figure 3.4.

(a)

(b)

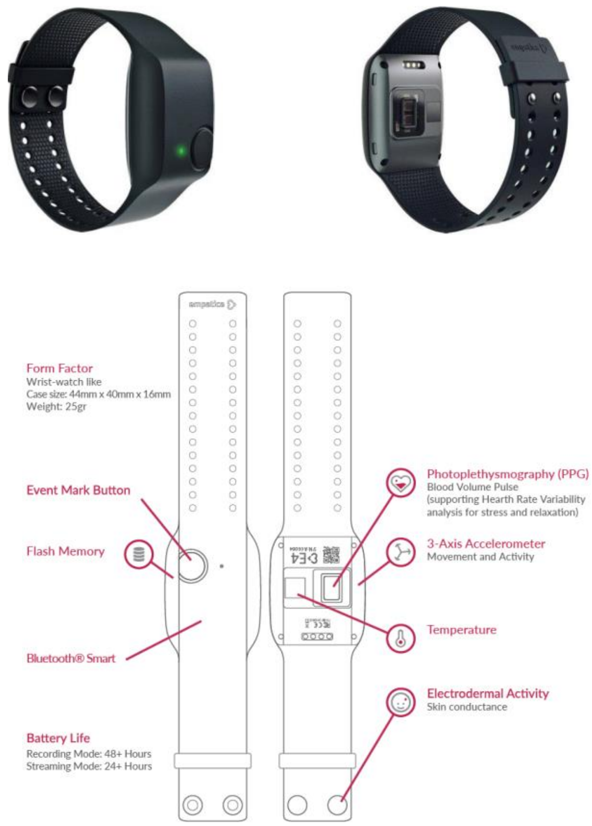


Figure 3.4 (a) E4 Empatica Wristband [71] (b) Sensors in E4 Wristband [71]

3.2.4 Experimental Design

The study used a mixed factorial design (2×2×2×3; age * traffic volume * pedestrians * queue length). The between-subjects independent variable was the age (young versus old drivers). The within-subjects independent variables were the traffic volume (high versus low), pedestrians (with pedestrians versus without pedestrians), and queue length (zero versus one versus two).

Each participant drove all twelve scenarios, presented to them in a pseudo-random order. No driver experienced a scenario twice. All these scenarios were implemented in the daytime. Each of these scenarios had the same speed limit, which was conveyed through the sign board in the simulation as well as they were mentioned before each drive. The scenario order was counter-balanced across subjects.

For both age groups, the high-traffic volume scenarios were completed first, and then the low-traffic scenarios. Moreover, 10 participants from the old age group did scenarios without pedestrians first and then with pedestrians one. The same order was followed for the participants from the younger age group. In both age groups, half of the participants completed zero queue length first then was followed by one and two, but another half of the participants completed two queue lengths first followed by zero then one queue length scenarios.

3.2.5 Dependent and Independent Variables

The dependent and independent variables are summarized in Table 3.2. The accepted gap of the drivers while taking a left turn at the four-way intersections is measured in seconds. The literature review from [26,50] concludes that one of the convenient and easier methods to detect gaps is the car turning time and, in this study, the gap was measured from the video data that the eye-tracker recorded during the entire experiment. Gap acceptance is defined as the process that occurs when the opposite traffic must either cross or merge with another traffic stream. The Gap is defined as the distance between the left turning vehicle and the oncoming traffic. The accepted gap was measured from the video of the eye-tracker. Rejected gap refers to a situation where a driver waits for a gap in oncoming traffic to turn left, but ultimately decides not to take that gap and waits for another opportunity to turn. In other words, a rejection gap occurs when a driver does not accept an available gap to make a left turn. The rejected gap was also collected from the video of the scenario produced by the eye-tracker.

The factors that affect gap acceptance behavior include age, traffic volume, queue length, HRV, EDA, and MSSQ scores. The age of the participants was collected from a demographic questionnaire administered before the start of the experiment. Traffic volume also varied from low to high to observe any effect on the participants while taking left turns.

Table 3.2 Overview of dependent and independent variables

Construct	Type of Variable	Unit
Accepted Gap	Dependent Variable	Seconds (s)
Rejected Gap	Dependent Variable	Count
Age	Independent Variable	Count
Traffic Volume	Independent Variable	Count
Queue Length	Independent Variable	Count
HRV	Independent Variable	ms
EDA	Independent Variable	Micro-Siemens (μS)
MSSQ	Independent Variable	Score

The queue length also varied from zero to two to check the changes that participants adopt while accepting the gap. The EDA values are collected from the E4 Empatica wristband and were checked against the accepted gap. The heart rate variability is calculated from the IBI (Inter-Beat Interval) time series data. There are three ways in which HRV can be calculated using IBI: time-domain analysis, frequency-domain analysis, and non-linear analysis [92-94]. Time-domain analysis is a straightforward statistical method that can be used to find the HRV values [98]. In time-domain analysis, there are many ways, such as the Standard Deviation of all NN intervals (SDNN), the root mean square of successive differences (RMSSD), and the percentage of differences between adjacent NN intervals that are greater than 50 ms (pNN50) [96-97,99]. Therefore, in this study, time-domain analysis is chosen and calculated by computing the SDNN of IBI. IBI is a sequence of time intervals between successive R-peaks, the NN interval refers to the interval between successive R waves.

The SDNN is calculated using the formula below [97,99]:

SDNN = sqrt ((1 / (n-1)) * ((IBI1 - Mean NN interval) ^2 + (IBI2 - Mean NN interval)^2 + ...+ (IBIn - Mean NN interval)^2))

Where n is the total number of NN intervals, IBI is the individual interval in milliseconds, and the mean NN interval is the average of all NN intervals. The MSSQ score was calculated from the MSSQ questionnaire that participants filled out before the start of the experiment.

3.2.6 Driving Scenarios

The overview of the scenarios can be seen in Table 3.3. All scenarios were based on four-way permissive intersections, in which participants were asked to make left turns. This study deals with permissive left turns, not protected left turns, where there is no left turn arrow or green light indicating that it is safe to turn. Instead, the driver must yield to oncoming traffic and pedestrians before making the left turn.

Traffic volume, queue length, and the presence of pedestrians varied in all scenarios, which all had a speed limit of 60 km/hr and took place on a four-way lane road, but there was a situation where the participants had to cross one two-way lane road. The traffic was scripted in all scenarios; 300 vehicles in higher traffic conditions, and 150 vehicles in lower traffic conditions, corresponding to the total number of vehicles in the entire scenario. In higher traffic scenarios, there were more oncoming vehicles, while in lower traffic scenarios, there were fewer oncoming vehicles. All higher and lower traffic scenarios had situations with zero, one, and two queue lengths, and these scenarios were also performed with and without pedestrians. The route in which the participant had to follow in all the scenarios was played as an audio throughout the experiment, and based on the route the participants complete their scenario. Figure 3.5 shows the different queue lengths used in the experiment.

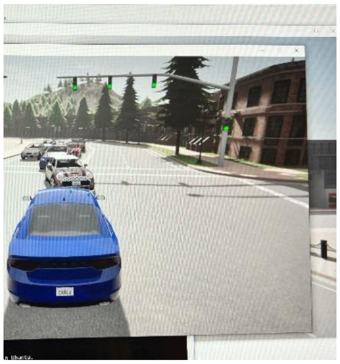


Figure 3.5 Car attempting to make a left turn

(a) (b) (c)

Figure 3.6 (a) Zero Queue Length (b) One Queue Length (c) Two Queue Length

Figure 3.7 Traffic Signage of the Experiment

Figure 3.8 Crossing of Pedestrian

The gap was measured from the video data, and it was as the distance between the left turning vehicle and the oncoming traffic. Figure 3.6 shows the traffic signage that was used during the experiment, while Figure 3.7 shows pedestrians crossing the road at the intersections.

Table 3.3 Driving Scenarios

Scenario Type	Traffic Volume	Pedestrians	Queue Length	Scenario No.
Four-way Intersection (60 Km /hr)	High (Number of Vehicles 300)	With pedestrians Without pedestrians	Zero queue length One queue length Two queue length	Scenario1 Scenario 2 Scenario 3 Scenario 4 Scenario 5 Scenario 6
	Low (Number of Vehicles 150)	With pedestrians Without pedestrians	Zero queue length One queue length Two queue length	Scenario 7 Scenario 8 Scenario 9 Scenario 10 Scenario 11 Scenario 12

Chapter 4

Data Exploration

4.1 Driving Simulator Data

Each scenario was approximately 2 mins long, all twelve scenarios for each participant were first recorded using the recorder function in Carla. This recorder function stores the vehicle kinematics data as JSON and this JSON file were generated into CSV files. In this, the data is recorded at a frequency of 10 Hz (i.e., 10 times per second). The necessary data from the simulator is shown in Figure 4.1. A wide range of data is generated by this simulator,

1. Vehicle data: Data regarding the position, velocity, acceleration, and orientation of all the vehicles in the simulation.
2. Sensor data: Data from various sensors including cameras, lidars, radars, and GPS devices.
3. Control data: Data such as throttle, brake, and steering commands.
4. Metadata: Generates state and progress of simulation including Frame rate, simulation mode, and current time.
5. Debug data: Generates data for debugging and troubleshooting purposes including logs, error messages, and warnings.

Scenario	Ped	Traffic	Queue	ACCEPTEDOLD	Younger_driver	REJECTEDOLD	Gap_Rejected_young
1	No	High	1	4.214	3.29	3	0
2	Yes	High	1	5.69	4.38	4	2
3	No	High	0	3.89	2.82	2	1
4	Yes	High	0	4.42	3.88	4	2
5	No	Low	0	3.4836	2.38	1	0
6	Yes	Low	0	3.82	2.445	3	0
7	No	Low	1	3.37	2.63	3	0
8	Yes	Low	1	4.58	3.69	5	0
9	No	High	2	6.35	4.47	4	4
10	Yes	High	2	7.68	4.51	6	4
11	No	Low	2	5.59	3.28	4	0
12	Yes	Low	2	5.79	3.31	5	2

Figure 4.1 Measures from the driving simulator

The gap was collected from the video data that is stored by the eye-tracker. The gap is calculated as the distance between the left turning vehicle and the oncoming traffic [26,50]. For the accepted gap time interval only the vehicle kinematics data is stored and other data at other intervals are dropped. The following steps were performed for data cleaning:

1. Dropping the column which is not needed for analysis.

2. Filtering the data points based on the accepted gap interval.
3. Dealing with the missing data.
4. If outliers are found need to be removed or handled appropriately.

4.2 Physiological sensor data

Driving behavior is affected by different factors ranging from traffic conditions to many driver characteristics such as age, emotional state, aggressiveness, etc. [72] The effect of mental state/stress has a great impact on driver behavior at intersections and these stress levels are measured by heart rate and skin conductance also known as EDA [72]. These signals can be observed from sensors and are also used in this study.

The measurements for this study were collected from the E4 Empatica wristband worn by the participants during the trial sessions as well as during their driving sessions in the simulator. The measurement duration was controlled by using a button on the wristband. The measurement for this experiment was started when the trial sessions started and were stopped once these practice sessions were done and started again when the participant started actual experimental scenarios hence recording all the twelve scenarios in a single attempt. These physiological sensors transfer the data to a system in real-time which can be further converted into folders corresponding to each participant containing CSV files of Heart Rate, Electrodermal Activity, and IBI.

The following steps were followed for data cleaning:

1. The timestamps were generated by considering the initial timestamp as shown in Figure 4.2 in cell A1.

	A	B	D	E	F	G
1	1674396395		time @ 4 HZ	Value	time @ 1HZ	Value
2						
3	4		9:06:35 AM	0.733584	9:06:35 AM	0.733584
4	0.733584		9:06:35 AM	0.774819	9:06:36 AM	0.774819
5	0.774819		9:06:35 AM	0.744093	9:06:37 AM	0.744093
6	0.744093		9:06:35 AM	0.742813	9:06:38 AM	0.742813
7	0.742813		9:06:36 AM	0.744093	9:06:39 AM	0.744093
8	0.744093		9:06:36 AM	0.750494	9:06:40 AM	0.750494
9	0.750494		9:06:36 AM	0.745373	9:06:41 AM	0.745373
10	0.745373		9:06:36 AM	0.735131	9:06:42 AM	0.735131
11	0.735131		9:06:37 AM	0.737692	9:06:43 AM	0.737692
12	0.737692		9:06:37 AM	0.738972	9:06:44 AM	0.738972
13	0.738972		9:06:37 AM	0.744093	9:06:45 AM	0.744093
14	0.744093		9:06:37 AM	0.753055	9:06:46 AM	0.753055
15	0.753055		9:06:38 AM	0.753055	9:06:47 AM	0.753055

Figure 4.2 EDA data with timestamps at frequency 1Hz

2. The HRV data is generated from IBI as shown in Figure 4.3 the frequency of EDA is reduced from 4 Hz to 1 Hz. Synchronization is done by stepping down the frequency as shown in Figure 4.2.

	A	B	C	D
1	IBI	Average	Difference	HRV_SDNN
2	0.015625	0.470461	-0.454835526	0.197616269
3	0.921875	0.495729	0.426145833	0.166681843
4	0.640625	0.470662	0.169963235	0.143621518
5	0.375	0.460039	-0.085039063	0.143475163
6	0.29375	0.465708	-0.171958333	0.145533192
7	0.53125	0.477991	0.053258929	0.140280298
8	0.4375	0.473894	-0.036394231	0.145530683
9	0.421875	0.476927	-0.055052083	0.149737354
10	0.968125	0.481932	0.486193182	0.153120474
11	0.583125	0.433313	0.1498125	0.073220125
12	0.390625	0.416667	-0.026041667	0.060142035

Figure 4.3 Heart Rate Variability data generated from IBI using SDNN

All the demographic information's filled in by the participants. The MSSQ score is also considered while analyzing the physiological features. Exploratory Data Analysis was performed in detail and is discussed as follows.

4.3 Exploration and Observation

Exploratory data analysis was performed for a variety of reasons such as to understand the data and to identify patterns, and relationships between the variables. This is also performed to detect any outliers, missing values, and other anomalies in the data that could affect the results of any subsequent analysis. This exploration also helps to select the appropriate statistical methods to use for further analysis based on the nature of the data.

The demographic information about the participants, which includes their age, experience, and driving license information were all tabulated together. The MSSQ score was calculated from the Motion Sickness questionnaire obtained from the participants. This was also included with demographic information.

Initially, a comparative graph analysis is performed for the accepted gap of both young and older drivers against varying queue lengths as shown in Figure 4.4. There was a huge difference between the accepted gap interval between young and elderly drivers. When considering 0 queue length, the maximum gap accepted time by the older adults was 5.43 seconds and the minimum gap accepted time was 2.84 seconds, in queue length 1 the maximum gap accepted time by the older adults was 6.17 seconds and the minimum gap accepted time was 2.99 seconds and in queue length 2, the maximum gap accepted time by the older adults was 8.15 seconds and the minimum gap accepted time was 2.86 seconds. When considering 0 queue length, the maximum gap accepted time by the younger drivers was 4.16 seconds and the minimum gap accepted time was 2.05 seconds, in queue length 1 the maximum gap accepted time by the younger drivers was 4.67 seconds and the minimum gap accepted time was 2.03 seconds and in queue length 2, the maximum gap accepted time by the younger drivers was 5.98 seconds and the minimum gap accepted time was 2.05 seconds. From Figure 4.4 it is evident that older drivers accept longer gaps when exposed to longer queue lengths compared to younger drivers.

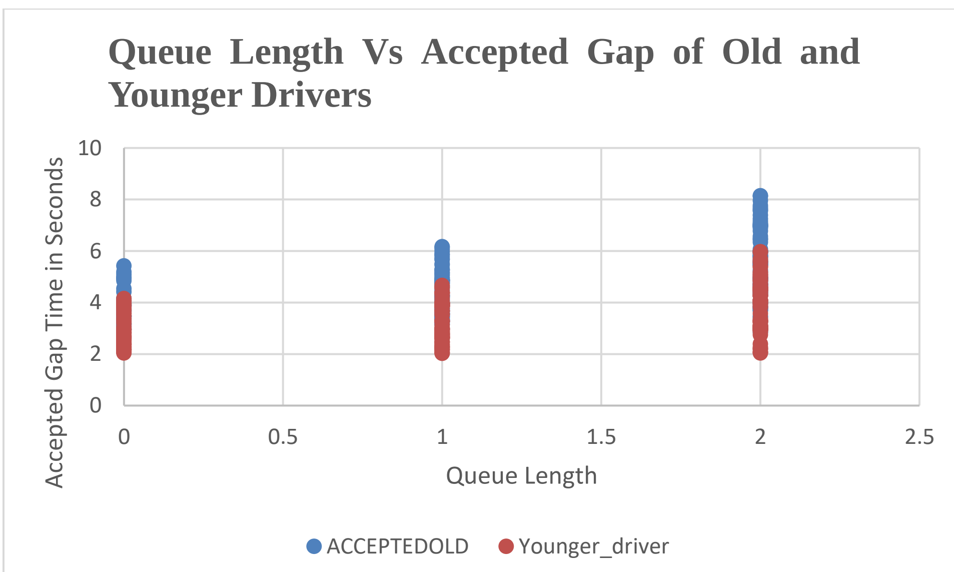


Figure 4.4 Comparative graph analysis for the accepted gap interval between young and older drivers against queue length

The accepted Gap value was also analyzed against the density of the traffic shown in Figures 4.5 and 4.6 for higher-density and lower-density traffic respectively. When considering higher traffic volume, the maximum gap accepted time by the older adults was 8.15 seconds and the minimum gap accepted time was 2.97 seconds and the maximum gap accepted time by the younger drivers was 5.98 seconds and the minimum gap accepted time was 2.19 seconds. When considering lower traffic volume, the maximum gap accepted time by the older adults was 6.48 seconds and the minimum gap accepted time was 2.84 seconds and the maximum gap accepted time by the younger drivers was 3.99 seconds and the minimum gap accepted time was 2.03 seconds. Older drivers accept longer gaps when exposed to higher traffic volume when compared to younger drivers.

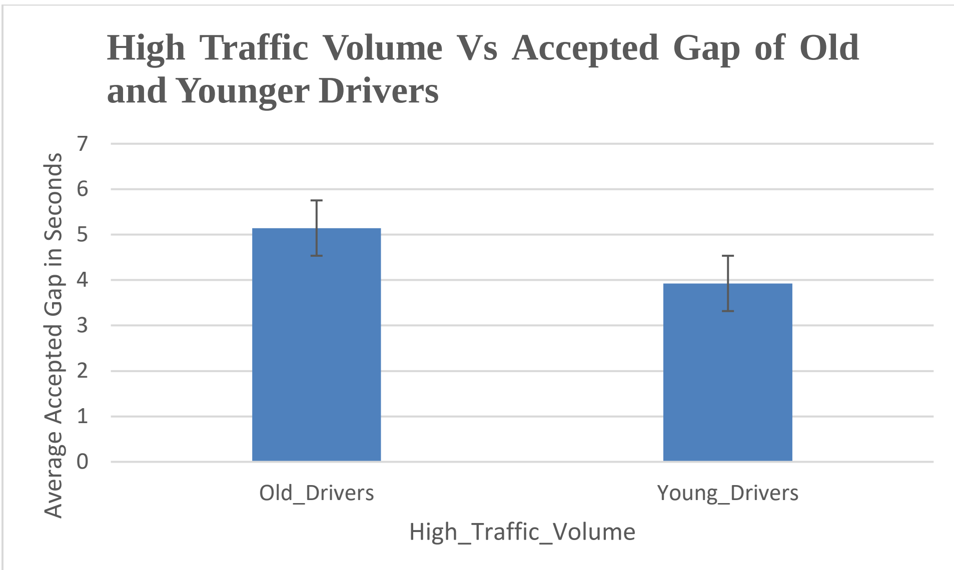


Figure 4.5 High Traffic Volume Vs Accepted Gap between Old and Younger Drivers

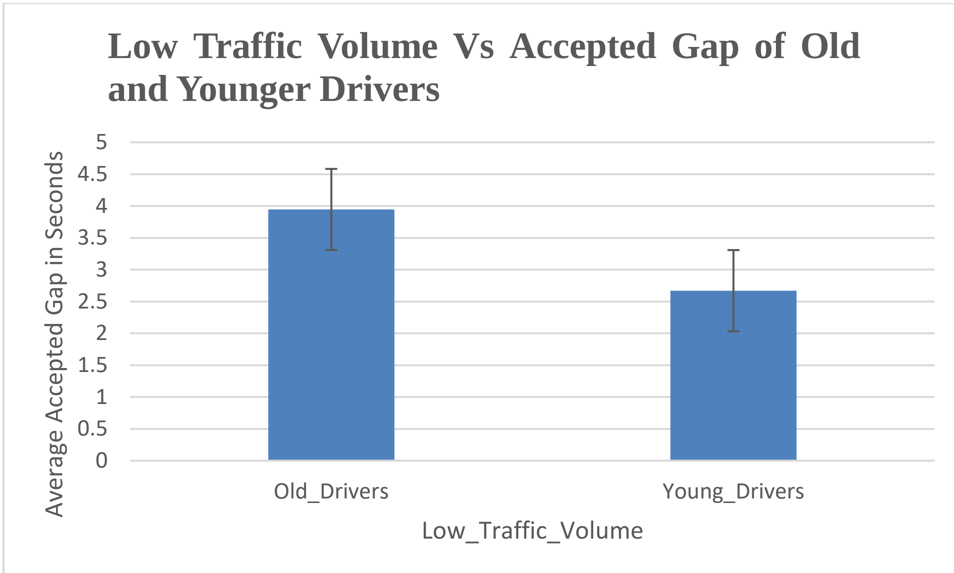


Figure 4.6 Low Traffic Volume Vs Accepted Gap between Old and Younger Drivers

The accepted Gap value was also analyzed against the presence and without the presence of pedestrians shown in Figures 4.7 and 4.8 respectively. When considering the presence of pedestrians, the maximum gap accepted time by the older adults was 8.15 seconds and the minimum gap accepted time was 3.06 seconds and the maximum gap accepted time by the younger drivers was 5.98 seconds and the minimum gap accepted time was 2.14 seconds. When considering the presence of pedestrians, the maximum gap accepted time by the older adults was 7.97 seconds and the minimum gap accepted time was 2.84 seconds and the maximum gap accepted time by the younger drivers was 4.98 seconds and the minimum gap accepted time was 2.03 seconds. Older drivers accept longer gaps when pedestrians are crossing the road while attempting to take left turns.

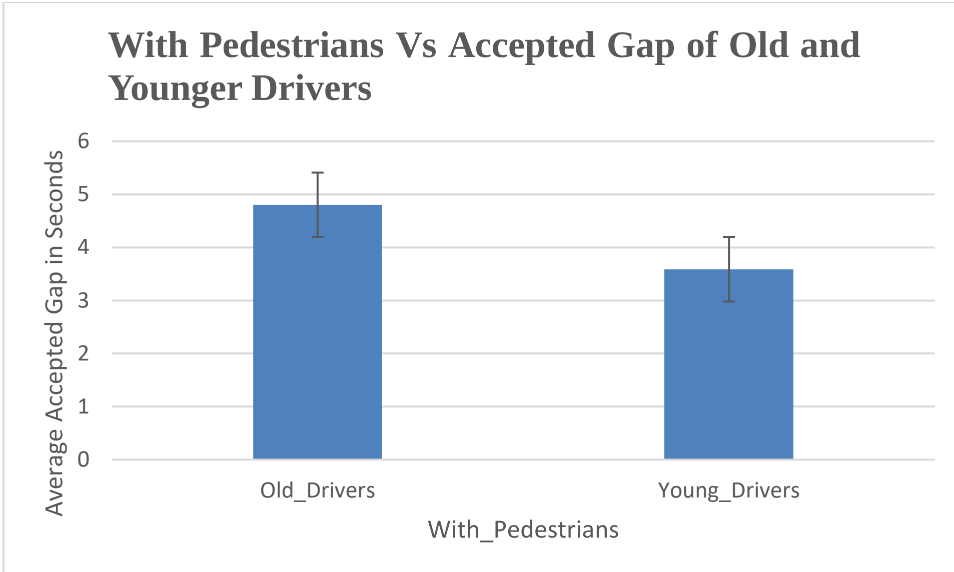


Figure 4.7 With Pedestrians Vs Accepted Gap between Old and Younger Drivers

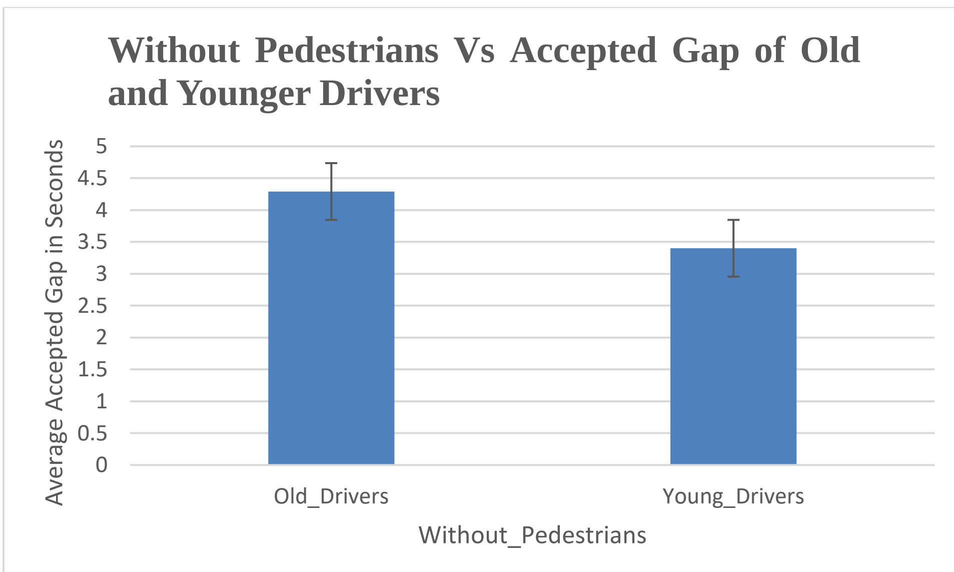


Figure 4.8 Without Pedestrians Vs Accepted Gap between Old and Younger Drivers

Rejected Gap count was also analyzed against the varying queue length as shown in Figure 4.9. At 0 queue length, the older adults at the maximum rejected 4 safe gaps, at 1 queue length they rejected 5 safe gaps and at 2 queue length, they rejected 8 gaps that are safe to make a left turn. On the other hand, at 0 queue length, the younger drivers at the maximum rejected 3 safe gaps, at

1 queue length they rejected 2 safe gaps and at 2 queue length, they rejected 4 gaps that are safe to make a left turn.

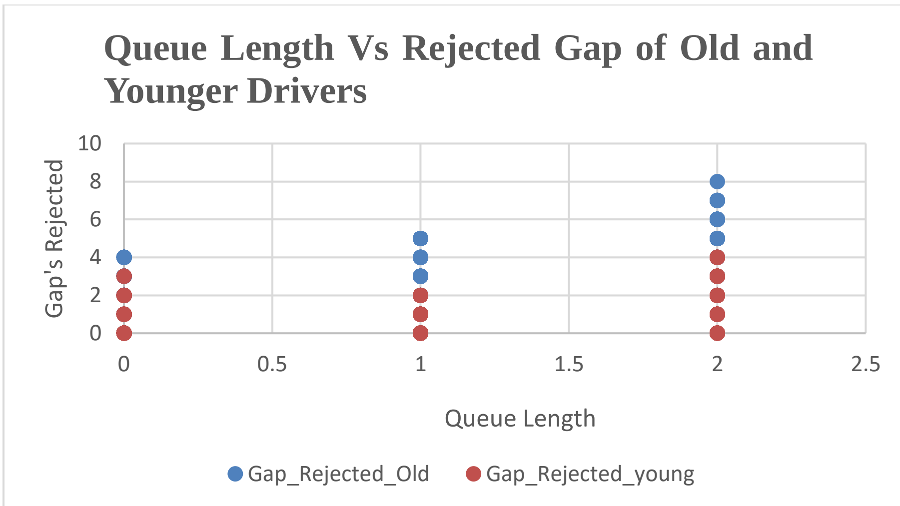
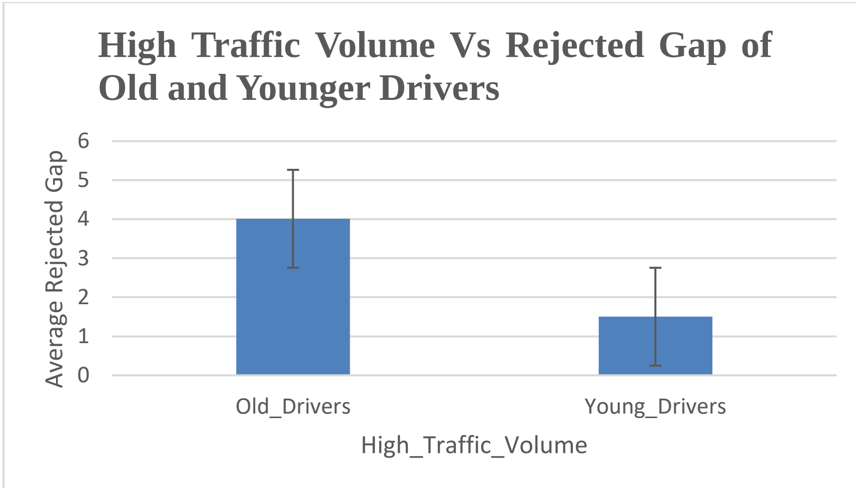


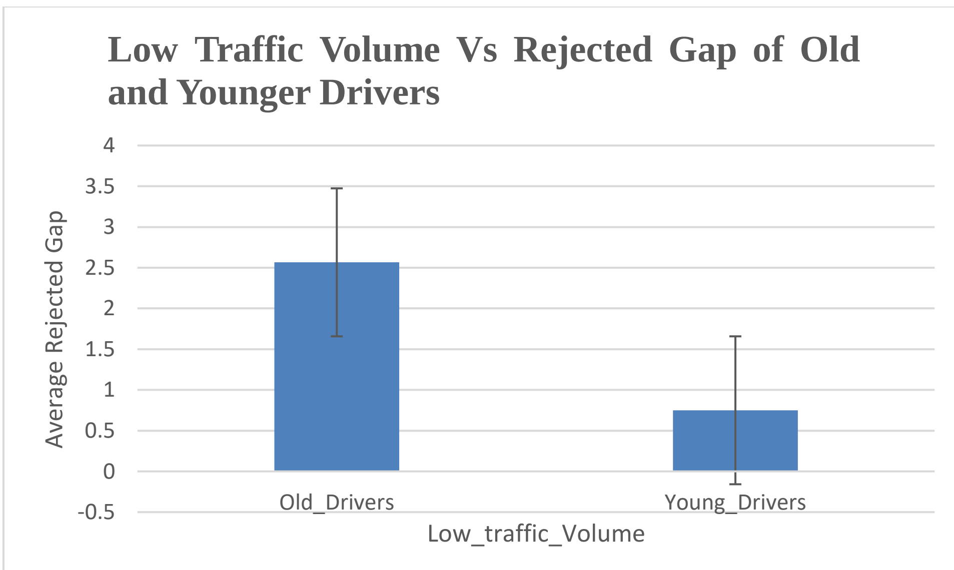
Figure 4.9 Queue Length Vs Rejected Gap of Old and Younger Drivers

Rejected Gap count was also analyzed against the varying traffic volume as shown in Figure 4.10 and Figure 4.11. At higher traffic volume, the older adults at the maximum rejected 8 safe gaps, and at lower traffic volume, the older adults at the maximum rejected 6 safe gaps. On the other hand, at higher traffic volume, the younger drivers at the maximum rejected 4 safe gaps, and at lower traffic volume, the older adults at the maximum rejected 3 safe gaps.



Error bars: 95% CI

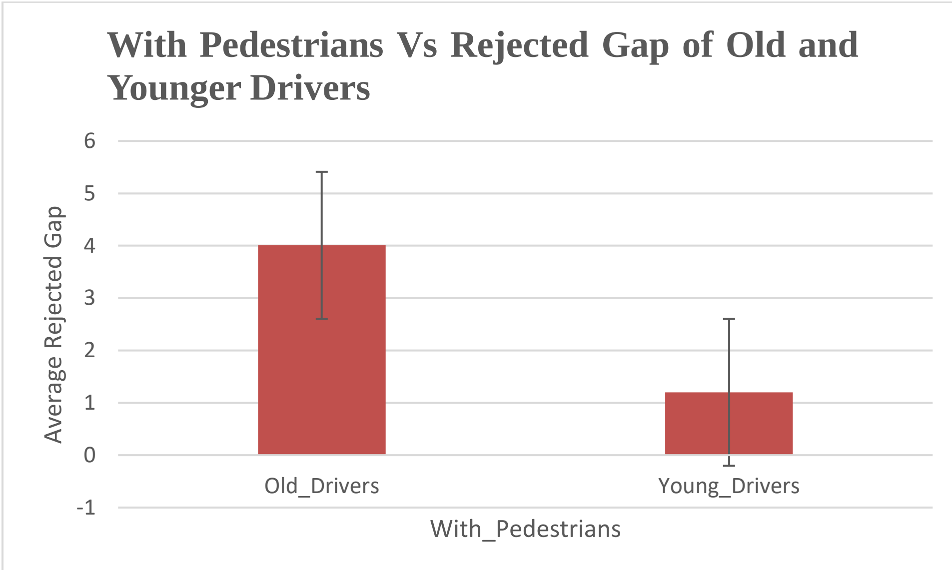
Figure 4.10 High Traffic Volume Vs Rejected Gap of Old and Younger Drivers



Error bars: 95% CI

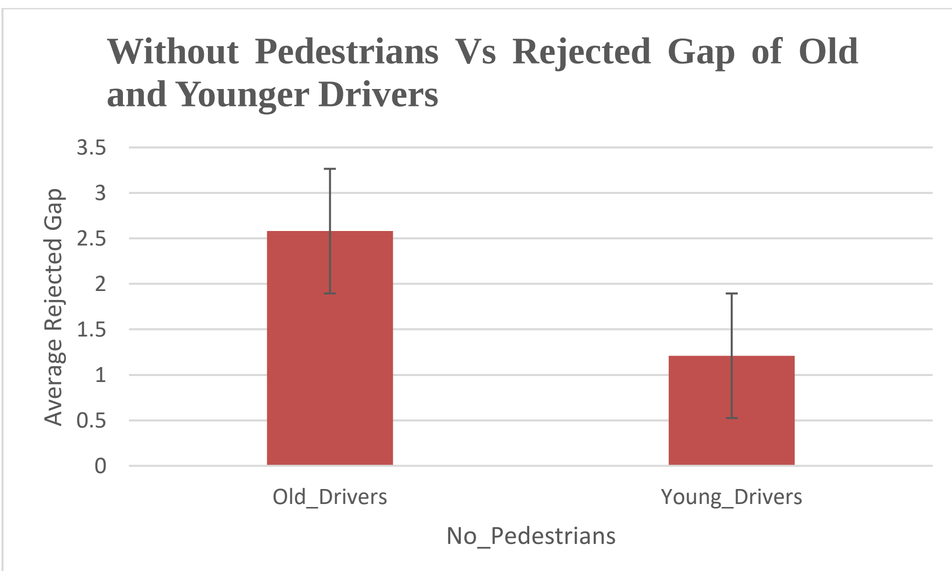
Figure 4.11 Low Traffic Volume Vs Rejected Gap between Old and Younger Drivers

Rejected Gap count was also analyzed against the presence and without the presence of pedestrians shown in Figures 4.12 and 4.13 respectively. With the presence of pedestrians, the older drivers rejected at the maximum of 8 safe gaps, and younger drivers rejected at the maximum of 4 safe gaps. Without the presence of pedestrians, the older drivers rejected at the maximum of 6 safe gaps, and younger drivers rejected at the maximum of 4 safe gaps.



Error bars: 95% CI

Figure 4.12 With Pedestrians Vs Rejected Gap between Old and Younger Drivers



Error bars: 95% CI

Figure 4.13 Without Pedestrians Vs Rejected Gap between Old and Younger Drivers

The EDA and HRV values are analyzed for same old aged and young aged driver. The EDA values are analyzed separately for a single young driver while taking a left and when waiting to take the left turn as shown in Figures 4.14 and 4.15. These EDA values remain the same for this driver while taking the left turn and when waiting to take the left turn. There is not much difference in the values of EDA in these two situations.

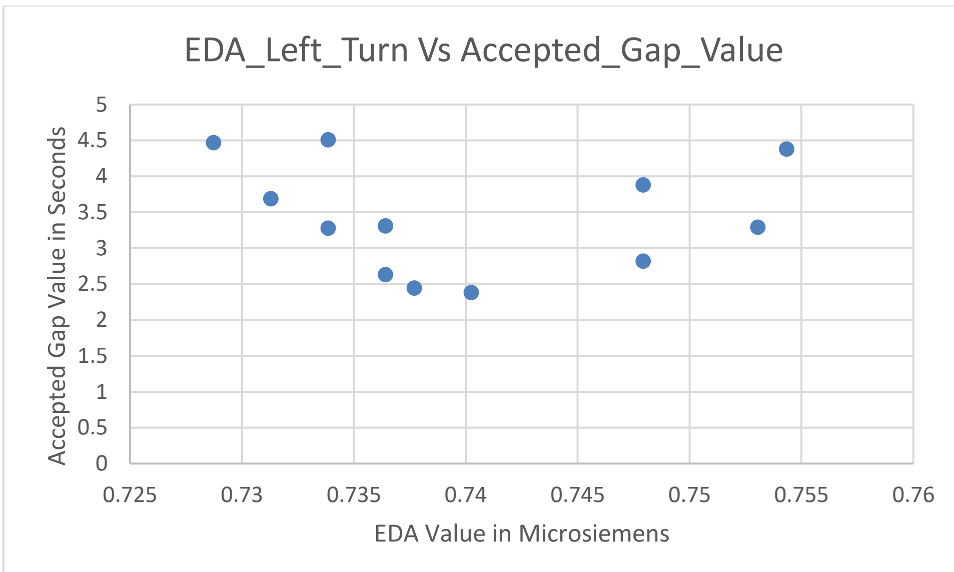


Figure 4.14 Analysis of EDA while turning left and the gap acceptance value of a single young age participant

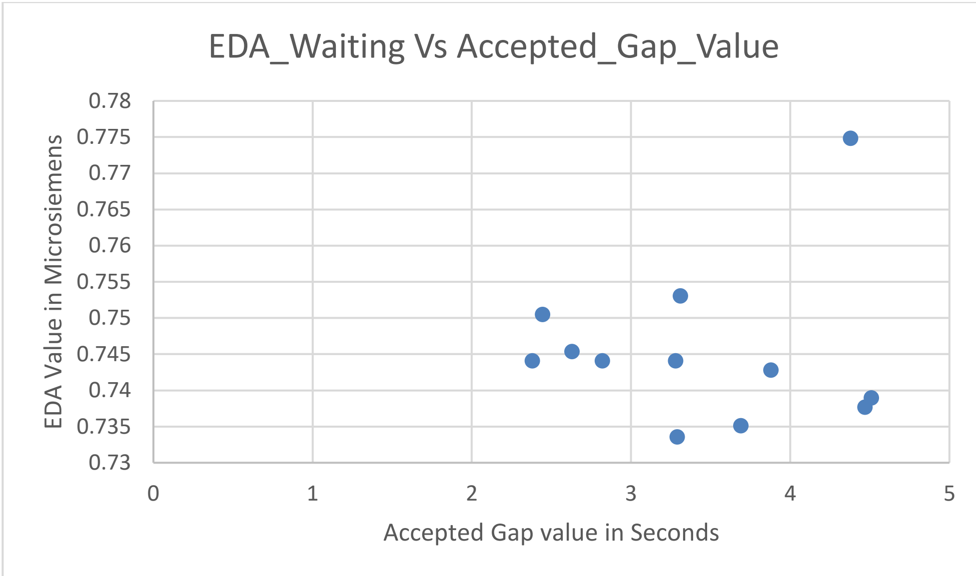


Figure 4.15 Analysis of EDA Value while waiting to make a left turn and the accepted gap value of a single young age participant

The EDA values are analyzed separately for a single old, aged driver while taking a left and when waiting to take the left turn as shown in Figures 4.16 and 4.17. These EDA values remain the same for this driver while taking the left turn and when waiting to take the left turn. There is not much difference in the values of EDA in these two situations.

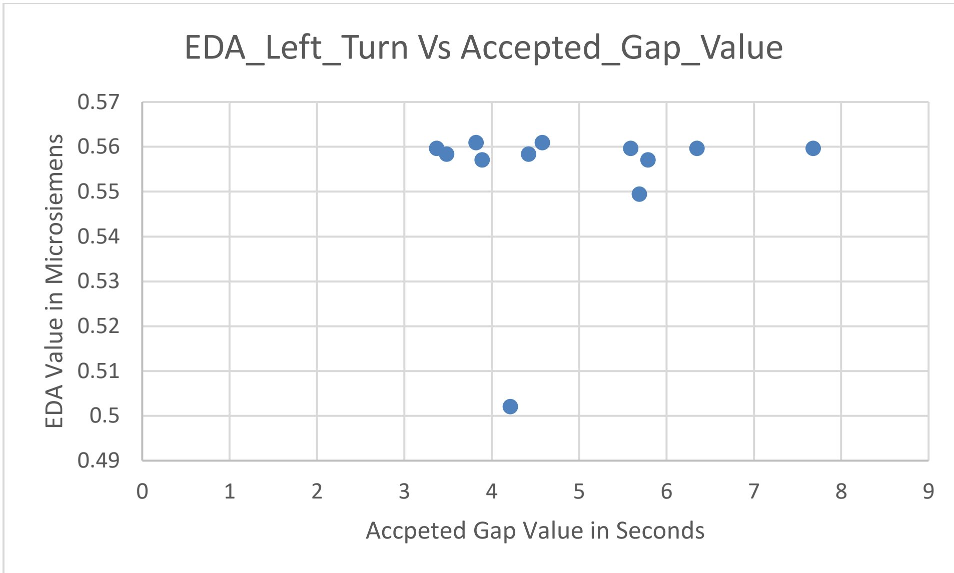


Figure 4.16 Analysis of EDA while turning left and the gap acceptance value of a single old age participant

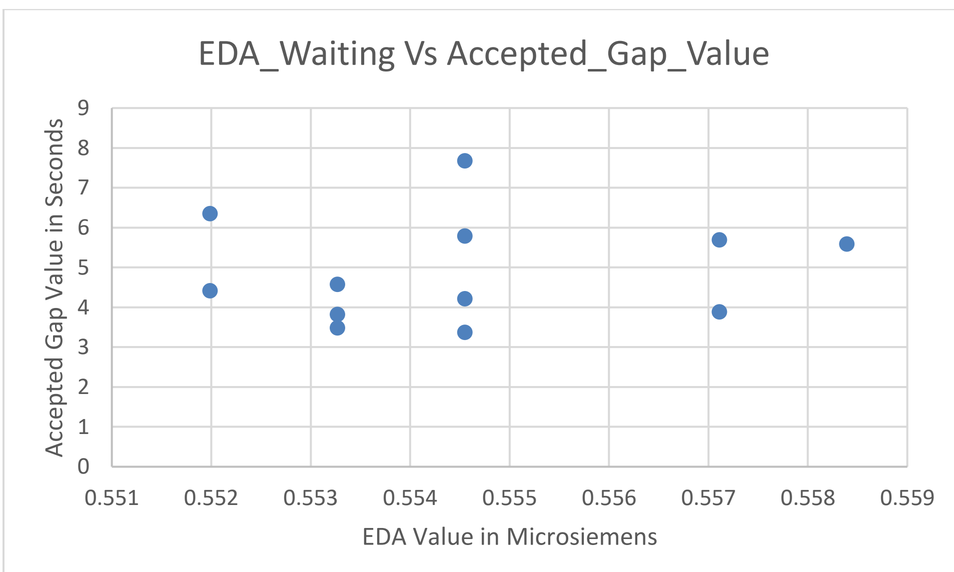


Figure 4.17 Analysis of EDA Value while waiting to make a left turn and the accepted gap value of a single old age participant

The HRV values are analyzed separately for a single old, aged driver while taking a left and when waiting to take the left turn as shown in Figures 4.18 and 4.19. The highest HRV of this driver while taking left turn was 3.0763 seconds and the highest HRV of this driver when waiting to take left turn was 1.267 seconds.

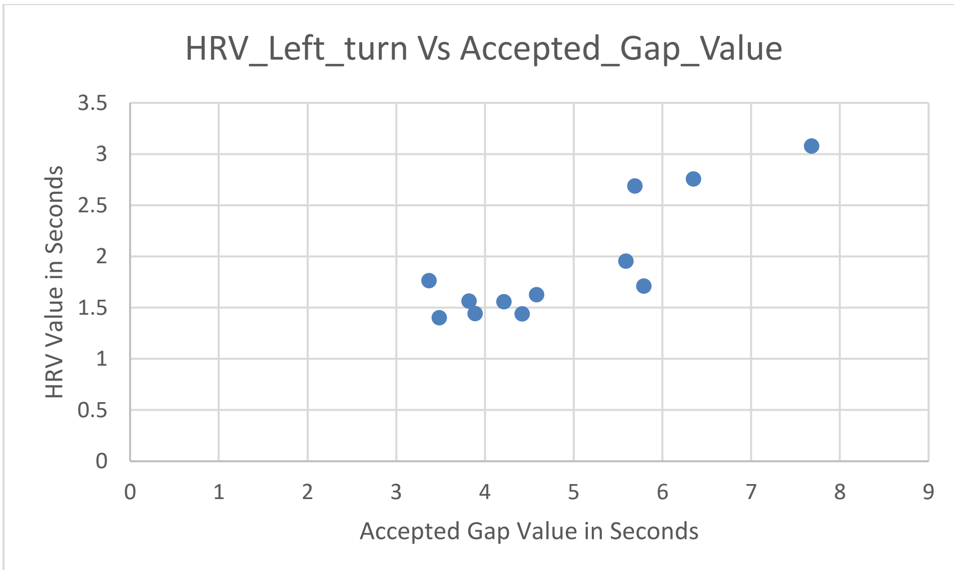


Figure 4.18 Analysis of HRV while turning left and the gap acceptance value of a single old age participant

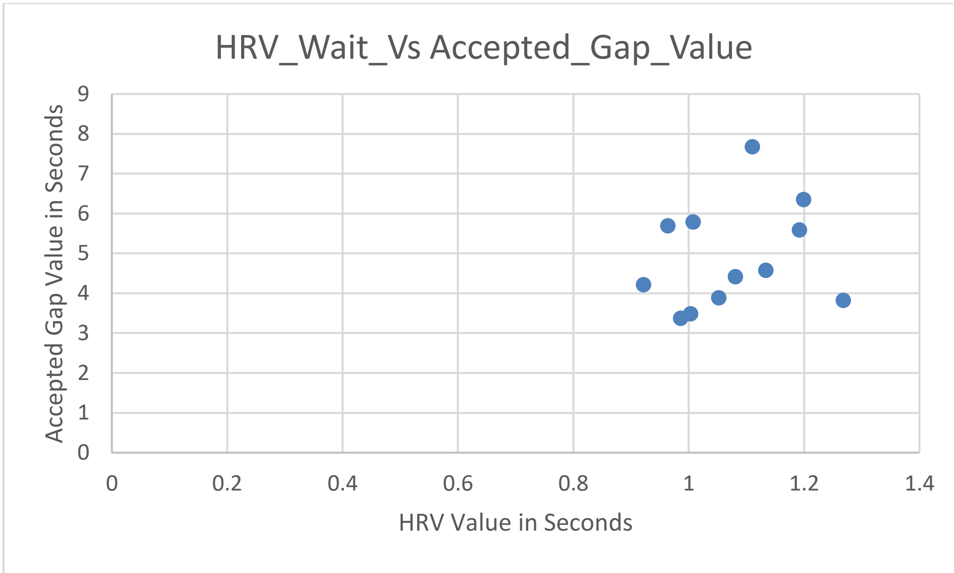


Figure 4.19 Analysis of HRV Value while waiting to make a left turn and the accepted gap value of a single old age participant

The HRV values are analyzed separately for single young, aged driver while taking a left and when waiting to take the left turn as shown in Figures 4.20 and 4.21. The highest HRV of this driver while taking left turn was 0.46799 seconds and the highest HRV of this driver when waiting to take left turn was 0.14045 seconds. The older driver's HRV is more while turning left in compared to the younger driver's HRV while turning left.

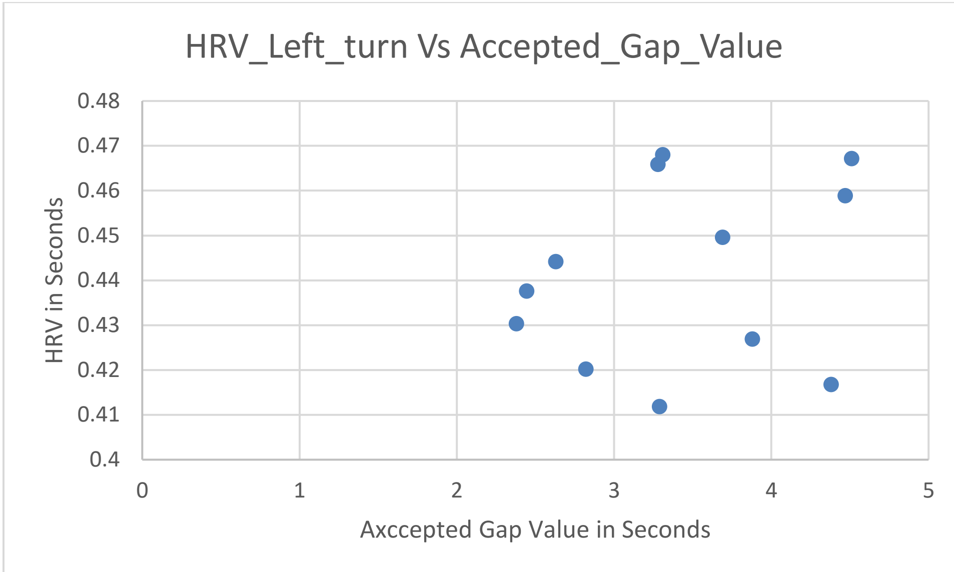


Figure 4.20 Analysis of HRV while turning left and the gap acceptance value of a single young age participant

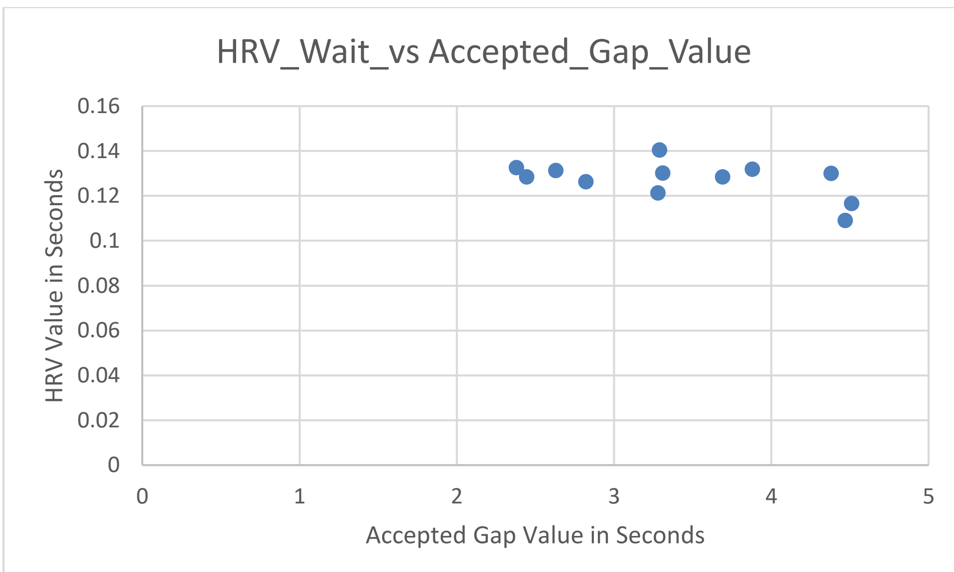


Figure 4.21 Analysis of HRV Value while waiting to make a left turn and the accepted gap value of a single young age participant

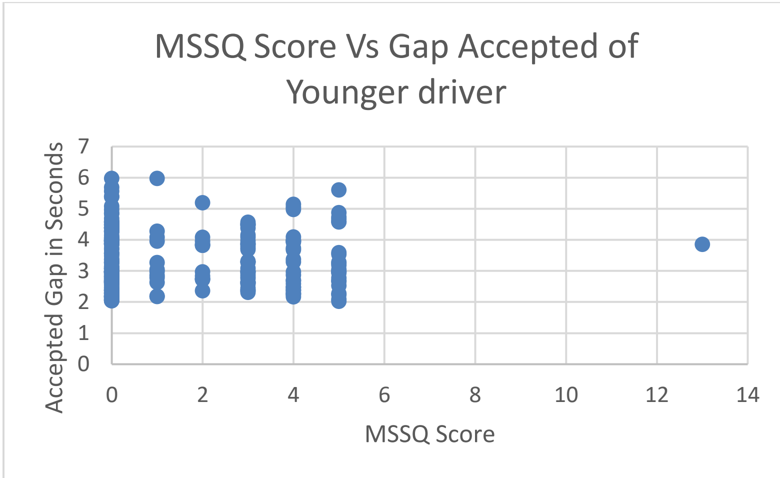


Figure 4.22 MSSQ score vs Gap length of the younger drivers

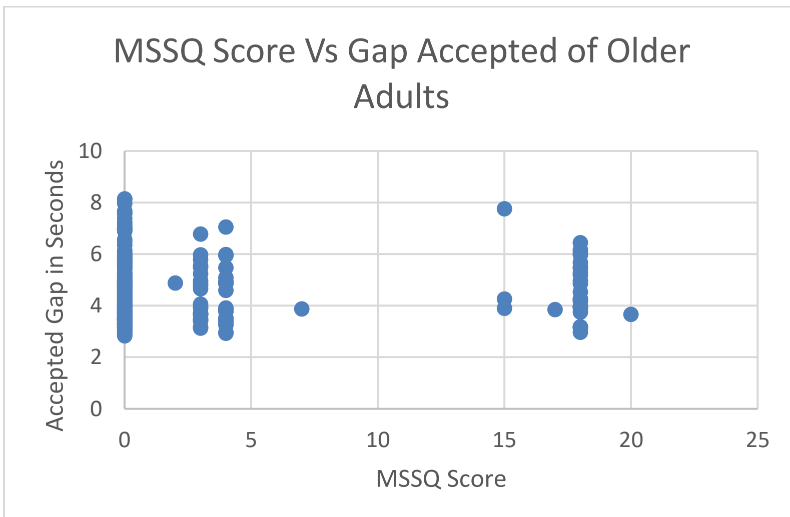


Figure 4.23 MSSQ Vs Gap length of older drivers

The accepted gap value tends to increase when the MSSQ score increases for the older drivers as seen in Figure 4.23.

4.4 Insights Obtained

From the study, queue length, traffic volume, and pedestrians have an impact on the accepted gap for both young and older drivers. However, there is only a mild change in the gap accepted time in younger drivers when considering all these factors, whereas older drivers gap acceptance behavior is affected by traffic volume, queue length, presence of pedestrians and the heart rate variability. At high traffic volume, the older adults took a maximum of 8.15 seconds to make a safe left turn, and at lower traffic, they took a maximum of 6.48 seconds, whereas the younger adults took a maximum of 5.98 seconds at higher traffic and a maximum of 3.99 seconds at lower traffic. Similarly, at 2 queue lengths, the older adults took a maximum of 8.15 seconds, and younger adults took 5.98 seconds, and with the presence of pedestrians, the older adults took a maximum of 8.15 seconds, and younger adults took 5.98 seconds. With all of this, traffic volume, queue length, and the presence of pedestrians have more impact on older adults than younger drivers. Even the older adults rejected a maximum of 8 gaps at higher traffic, higher queue length, and with the presence of pedestrians, whereas younger drivers only rejected 4 gaps at higher traffic, higher queue length, and with the presence of pedestrians.

The physiological responses, such as heart rate variability calculated from the IBI, also show an impact on the gap accepted by the older drivers. As the heart rate variability increases, the accepted gap time also increases and decreases with the decrease in heart rate variability. In the case of younger drivers, there is a change in the accepted gap time, but heart rate variability does not have more impact on younger drivers when compared to older drivers. The EDA values for both young and older drivers remain the same in all situations.

The observations from the questionnaire obtained from the participants show that participants with higher motion sickness in older and younger drivers tend to accept a longer gap. For older drivers, queue length, traffic volume, pedestrians, HRV, and MSSQ score affect the time in which they tend to make a safer left turn, whereas the younger driver’s left turn is majorly affected by the traffic volume and pedestrians. These factors help us understand the accepted gap time and the reason for accepting long gaps at intersections. Overall, elder drivers take longer than younger drivers to execute a safe left turn.

Chapter 5

Results and Discussion

The observations made from the previous chapter gives us insights into the factors that affect the accepted gap length for both the drivers and the factors that do not have more impact on the accepted gap length. Statistical analysis has been performed to find whether to accept the null hypothesis or reject them.

5.1 Results

There were 40 participants (20 Younger drivers of age 20-30 years and 20 elder drivers of age above 65 years) who took part in this study. Repeated Measures ANOVA for three within-subject factors was conducted using R-Language. Table 5.1 and Table 5.2 show the descriptive statistics for the accepted gap between older and younger drivers and the descriptive statistics for the rejected gap between older and younger drivers.

Table 5.1 Descriptive Statistics for Accepted Gap Value of Older and Younger Adults

	Mean	SD	Median	SE Mean	Kurtosis
Older Adults	4.544	1.21	4.197	0.078	0.28
Younger Drivers	3.312	0.908	2.99	0.0586	- 0.29

Table 5.2 Descriptive Statistics for Rejected Gap Value of Older and Younger Adults

	Mean	SD	Median	SE Mean	Kurtosis
Older Adults	3.291	1.7035	3	0.1099	- 0.45
Younger Drivers	1.1291	1.1625	1	0.0750	- 0.27

Tables 5.1 and 5.2 show the mean, the standard error of the mean (SE Mean), the standard deviation of the median, and the kurtosis of older and younger drivers when they are accepting a gap and rejecting a gap respectively. For the accepted gap value, the older adults had a mean score of 4.544. The standard error of the mean is 0.078, indicating that the sample mean is likely to be close to the true population mean. The kurtosis value of 0.28 suggests that the distribution is relatively normal. For the accepted gap value, the younger drivers had a mean score of 3.312. The standard error of the mean is 0.0058, indicating that the sample mean is likely to be close to the true population mean. The kurtosis value of - 0.29 suggests that the distribution is relatively flat, and there are no significant outliers.

For the rejected gap count, the older adults had a mean score of 3.291. The standard error of the mean is 0.1099, indicating that the sample mean is likely to be close to the true population mean. The kurtosis value of - 0.45 suggests that the distribution is relatively flat, and there are no significant outliers. For the rejected gap count, the younger drivers had a mean score of 1.129. The standard error of the mean is 0.0750, indicating that the sample mean is likely to be close to the true population mean. The kurtosis value of - 0.27 suggests that the distribution is relatively flat, and there are no significant outliers.

T-Test is conducted for the Accepted Gap Value against Younger and Older drivers it’s seen that P-Value is less than 0.05 and for the Rejected Gap Value against Younger and Older drivers it’s seen that P-Value is less than 0.05. Hence the Null Hypothesis is defined as, H0: there is no change in the gap accepted values between young and old age drivers, and the alternative Hypothesis, HA: there is a change in the gap accepted values between young and old age drivers. The alternative hypothesis is accepted as the P-value is less than 0.05. Hence the Null Hypothesis is defined as, H0: there is no change in the gap rejected values between young and old age drivers, and the alternative Hypothesis, HA: there is a change in the gap rejected values between young and old age drivers. The alternative hypothesis is accepted as the P-value is less than 0.05. These can be seen in Table 5.3.

Table 5.3 T-Test for Accepted Gap and Rejected Gap of Older and Younger Drivers

	P-Value
Gap Accepted by Old Drivers Vs Gap Accepted by Young Drivers	$5.82e^{-32}$ *
Gap Rejected of Old Drivers Vs Gap Rejected of Young Drivers	$7.24e^{-48}$ *

Repeated Measures ANOVA is performed for the accepted gap value of older drivers and the results are shown in Table 5.4. When the Repeated Measures ANOVA test is conducted to analyze the accepted gap against queue length, traffic volume, and pedestrians it is seen that the p-value is lesser than 0.05, so the queue length, traffic volume, and pedestrians are statistically significant on the older driver's accepted gap. The *null hypothesis* H_o is stated as There is no significant difference in the mean accepted gap value between different queue lengths and *alternative hypothesis* H_A is stated as There is a significant difference in the mean accepted gap value between different queue lengths. The results from Table 5.3 show that the alternative hypothesis is accepted in the case of queue length. The *null hypothesis* H_o is stated as There is no significant difference in the mean accepted gap value between different traffic volumes and *alternative hypothesis* H_A is stated as There is a significant difference in the mean accepted gap value between different traffic volumes. The results from Table 5.4 show that the above alternative hypothesis is accepted in the case of traffic volume.

The *null hypothesis* H_o is stated as There is no significant difference in the mean accepted gap value between the presence of pedestrians. and *alternative hypothesis* H_A is stated as There is a difference in the mean accepted gap value between the presence of pedestrians.

The results from Table 5.4 show that the null hypothesis is rejected in the case of pedestrians and the model is getting improved by adding pedestrians. Table 5.4 results also prove one more null hypothesis is accepted. The *null hypothesis* H_o is stated as There is no change in older drivers' accepted gap values between varying queue length, traffic volume, and presence of pedestrians, and *alternative hypothesis* H_A is stated as There is a change in older drivers' accepted gap values between varying queue length, traffic volume and presence of pedestrians. In this case, also alternative hypothesis is accepted, and the null hypothesis is rejected.

Table 5.4 also shows the interaction effects between “Traffic: Queue”, “Traffic: Pedestrians”, “Queue: Pedestrians” and ‘Queue Length: Traffic Volume: Pedestrians’. The interaction between “Traffic: Queue” is 0.00417 which is less than 0.05 this means that there is evidence of a statistically significant interaction effect between the two independent variables on the dependent variable. The interaction between “Queue Length: Traffic Volume: Pedestrians’ is 0.01523 which is less than 0.05 this means that there is evidence of a statistically significant interaction effect between the two independent variables on the dependent variable.

Table 5.4 Repeated Measures Anova Results for Accepted Gap Value of Older Adults

	Df	Sum Sq	Mean Sq	F Value	P Value	Eta^2(Partial)
Traffic	1	1.37	1.362	3.818	0.05193 *	0.02
Queue	1	1.55	1.5497	4.331	0.03856 *	0.02
Ped	1	1.97	1.9693	5.503	0.01984 *	0.02
Traffic: Queue	1	3.00	2.9975	8.377	0.00417 *	0.04
Traffic: Ped	1	0.88	0.8805	2.461	0.11813	0.01
Queue: Ped	1	0.13	0.1264	0.353	0.55295	$1.56e^{-03}$
Traffic:Queue: Ped	1	2.14	2.1401	5.981	0.01523*	0.03

Repeated Measures ANOVA is performed for the accepted gap value of younger drivers and the results are shown in Table 5.5. When the Repeated Measures ANOVA test is conducted to analyze the accepted gap against queue length, traffic volume, and pedestrians it is seen that the p-value is lesser than 0.05, so the queue length, traffic volume, and pedestrians are statistically significant on the younger driver’s accepted gap. The *null hypothesis* H_o is stated as There is no significant difference in the mean accepted gap value between different queue length and *alternative hypothesis* H_A is stated as There is a significant difference in the mean accepted gap value between different queue length. The results from Table 5.5 show that the alternative hypothesis is accepted in the case of queue length. The *null hypothesis* H_o is stated as There is no significant difference in the mean accepted gap value between different traffic volume and *alternative hypothesis* H_A is stated as There is a significant difference in the mean accepted gap value between different traffic volume. The results from Table 5.5 show that the above alternative hypothesis is accepted in the case of traffic volume.

Table 5.5 Repeated Measures Anova Results for Accepted Gap Value of Younger Drivers

	Df	Sum Sq	Mean Sq	F Value	P Value	Eta²(Partial)
Traffic	1	1.1861	1.1861	15.763	$9.65e^{-05}$ *	0.07
Queue	1	2.264	2.264	19.175	$1.82e^{-05}$ *	0.08
Ped	1	8.744	8.744	74.062	$1.29e^{-05}$ *	0.25
Traffic: Queue	1	1.572	1.572	13.315	0.000327 *	0.06
Traffic: Ped	1	1.815	1.815	15.372	0.000117 *	0.06
Queue: Ped	1	1.052	1.052	8.907	0.003152 *	0.04
Traffic: Queue: Ped	1	0.143	0.143	1.211	0.272404	$5.33e^{-03}$

The *null hypothesis* H_o is stated as There is no significant difference in the mean accepted gap value between the presence of pedestrians and *alternative hypothesis* H_A is stated as There is a significant difference in the mean accepted gap value between the presence of pedestrians. The results from Table 5.5 show that the null hypothesis is rejected in the case of pedestrians. Table 5.5 results also prove one more null hypothesis is accepted. The *null hypothesis* H_o is stated as There is no change in younger drivers' accepted gap values between varying queue length, traffic volume, and presence of pedestrians, and *alternative hypothesis* H_A is stated as There is a change in younger drivers' accepted gap values between varying queue length, traffic volume and presence of pedestrians. In this case, the alternative hypothesis is accepted, and the null hypothesis is rejected.

Table 5.5 also shows the interaction effects between “Traffic: Queue”, “Traffic: Pedestrians”, “Queue: Pedestrians” and ‘Queue Length: Traffic Volume: Pedestrians’. The interaction between “Traffic: Queue” is 0.000327 which is less than 0.05 this means that there is evidence of a statistically significant interaction effect between the two independent variables on the dependent variable. The interaction between “Traffic Volume: Pedestrians’ is 0.000117 which is less than 0.05 this means that there is evidence of a statistically significant interaction effect between the two independent variables on the dependent variable. The interaction between “Queue: Pedestrians’ is 0.003152 which is less than 0.05 this means that there is evidence of a statistically significant interaction effect between the two independent variables on the dependent variable.

Table 5.6 Repeated Measures Anova Results for Rejected Gap Value of Older Adults

	Df	Sum Sq	Mean Sq	F Value	P Value	Eta^2(Partial)
Traffic	1	25.43	25.431	34.110	$1.80e^{-08*}$	0.13
Queue	1	11.95	11.955	16.034	$8.44e^{-05*}$	0.07
Ped	1	22.98	22.984	30.827	$7.88e^{-08*}$	0.12
Traffic: Queue	1	2.07	2.069	2.776	0.09710	0.01
Traffic: Ped	1	2.90	2.901	3.890	0.04978^{*}	0.02
Queue: Ped	1	12.53	12.535	16.812	$5.76e^{-05*}$	0.07
Traffic: Queue: Ped	1	5.04	5.036	6.755	0.00997^{*}	0.03

Repeated Measures ANOVA is performed for the rejected gap value of older drivers and the results are shown in Table 5.6. When the Repeated Measures ANOVA test is conducted to analyze the accepted gap against queue length, traffic volume, and pedestrians it is seen that the p-value is lesser than 0.05, so the queue length, traffic volume, and pedestrians are statistically significant on the older driver's rejected gap. The *null hypothesis* $\boldsymbol{H_o}$ is stated as There is no significant difference in the mean rejected gap value between different queue length and *alternative hypothesis* $\boldsymbol{H_A}$ is stated as There is a significant difference in the mean rejected gap value between different queue length. The results from Table 5.6 show that the alternative hypothesis is accepted in the case of queue length. The *null hypothesis* $\boldsymbol{H_o}$ is stated as There is no significant difference in the mean rejected gap value between different traffic volume and *alternative hypothesis* $\boldsymbol{H_A}$ is stated as There is a significant difference in the mean rejected gap value between different traffic volume. The results from Table 5.6 show that the above alternative hypothesis is accepted in the case of traffic volume.

The *null hypothesis* $\boldsymbol{H_o}$ is stated as There is no significant difference in the mean rejected gap value between the presence of pedestrians and *alternative hypothesis* $\boldsymbol{H_A}$ is stated as There is a significant difference in the mean rejected gap value between the presence of pedestrians. The results from Table 5.6 show that the null hypothesis is rejected in the case of pedestrians. Table 5.6 results also prove one more null hypothesis is accepted. The *null hypothesis* $\boldsymbol{H_o}$ is stated as There is no change in older drivers rejected gap values between varying queue length, traffic volume, and presence of pedestrians, and *alternative hypothesis* $\boldsymbol{H_A}$ is stated as There is a change in older drivers rejected gap values between varying queue length, traffic volume and presence of pedestrians. In this case, the alternative hypothesis is accepted, and the null hypothesis is rejected.

Table 5.6 also shows the interaction effects between "Traffic: Queue", "Traffic: Pedestrians", "Queue: Pedestrians" and 'Queue Length: Traffic Volume: Pedestrians'. The interaction between "Traffic: Pedestrians" is 0.04978 which is less than 0.05 this means that there is evidence of a statistically significant interaction effect between the two independent variables on the dependent variable. The interaction between "Queue: Pedestrians" is $5.7e^{-0.5}$ which is less than 0.05. This means that there is evidence of a statistically significant interaction effect between the two independent variables on the dependent variable. The interaction between "Queue Length: Traffic Volume: Pedestrians' is 0.00997 which is less than 0.05 this means that there is evidence of a statistically significant interaction effect between the two independent variables on the dependent variable.

Table 5.7 Repeated Measures Anova Results for Rejected Gap Value of Younger Drivers

	Df	Sum Sq	Mean Sq	F Value	P Value	Eta^2(Partial)
Traffic	1	0.03	0.0282	0.041	0.840	$1.81e^{-04}$
Queue	1	0.11	0.1094	0.158	0.691	$7.01e^{-04}$
Ped	1	0.04	0.0389	0.056	0.813	$2.49e^{-04}$
Traffic: Queue	1	0.14	0.1379	0.199	0.656	$8.81e^{-04}$
Traffic: Ped	1	0.89	0.8915	1.292	0.257	$5.68e^{-03}$
Queue: Ped	1	0.10	0.1010	0.146	0.702	$6.47e^{-04}$
Traffic: Queue: Ped	1	0.05	0.458	0.066	0.797	$2.93e^{-04}$

Repeated Measures ANOVA is performed for the rejected gap value of younger drivers and the results are shown in Table 5.7. When the Repeated Measures ANOVA test is conducted to analyze the rejected gap against queue length, traffic volume, and pedestrians it is seen that the p-value is greater r than 0.05, so the queue length, traffic volume, and the presence of pedestrians are not statistically significant on the younger driver's rejected gap. The *null hypothesis* $\boldsymbol{H_o}$ is stated as There is no significant difference between the rejected gap value and queue length and *alternative hypothesis* $\boldsymbol{H_A}$ is stated as There is a significant difference between the rejected gap value and queue length. The results from Table 5.7 show that the alternative hypothesis is rejected in the case of queue length. The *null hypothesis* $\boldsymbol{H_o}$ is stated as There is no significant difference between the rejected gap value and traffic volume and *alternative hypothesis* $\boldsymbol{H_A}$ is stated as There is a significant difference between the rejected gap value and traffic volume. The results from Table 5.7 show that the above null hypothesis is accepted in the case of traffic volume.

The *null hypothesis* $\boldsymbol{H_o}$ is stated as There is no significant difference between the rejected gap value and pedestrians and *alternative hypothesis* $\boldsymbol{H_A}$ is stated as There is a significant difference between the rejected gap value and pedestrians. The results from Table 5.7 show that the null hypothesis is accepted in the case of pedestrians. Table 5.7 results also prove one more null hypothesis is accepted.

The *null hypothesis* $\boldsymbol{H_o}$ is stated as There is no change in younger drivers rejected gap values between varying queue length, traffic volume, and presence of pedestrians, and *alternative hypothesis* $\boldsymbol{H_A}$ is stated as There is a change in younger drivers rejected gap values between varying queue length, traffic volume and presence of pedestrians. In this case, the alternative hypothesis is rejected, and the null hypothesis is accepted. Table 5.6 also shows the interaction effects between "Traffic: Queue", "Traffic: Pedestrians", "Queue: Pedestrians" and 'Queue Length: Traffic Volume: Pedestrians'. But for all of them, the P-Value is greater than 0.05 so, there is no interaction between the independent variables.

To check whether the model fits the assumption of homoscedasticity diagnostic plots were plotted in Figure 5.1 and this shows the unexplained variance (residuals) across the range of the observed data. The red line representing the mean of the residuals is horizontal and centered on zero or near one in the scale-location plot, meaning that there are no large outliers that would cause research bias in the model. The normal Q-Q plot plots a regression between the theoretical residuals of a perfectly homoscedastic model and the actual residuals of the current model. This Q-Q plot is very close, with only a bit of deviation. From these diagnostic plots as shown in Figure 5.1 it can be concluded that the model fits the assumption of homoscedasticity.

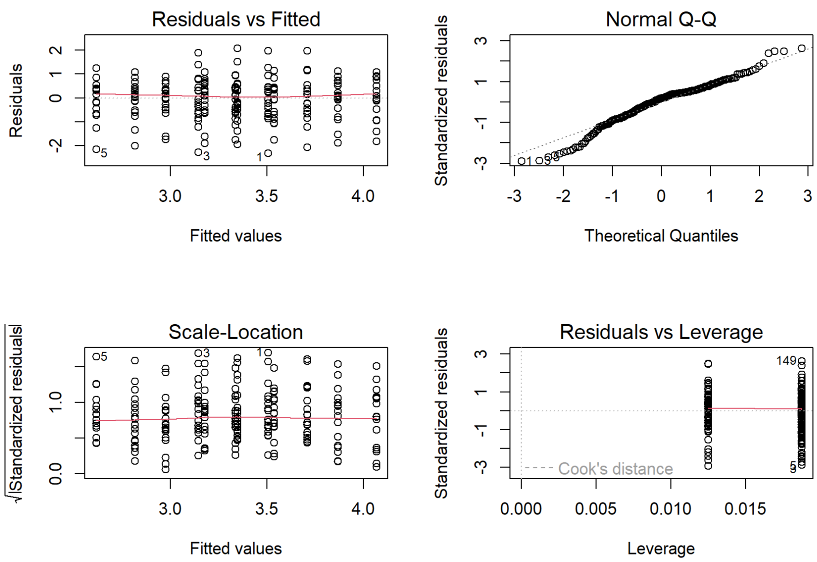


Figure 5.1 Homoscedasticity diagnostic plots for all the three factors of older drivers

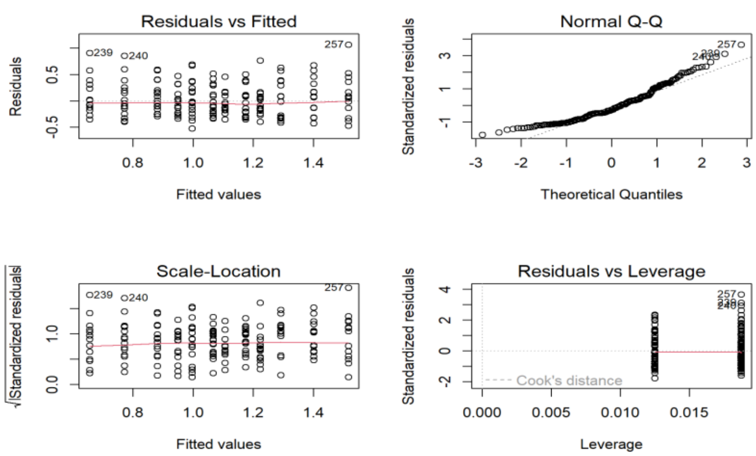


Figure 5.2 Homoscedasticity diagnostic plots for all the three factors of younger drivers

To check whether the model fits the assumption of homoscedasticity diagnostic plots were plotted in Figure 5.2 and this shows the unexplained variance (residuals) across the range of the observed data. The red line representing the mean of the residuals is horizontal and centered on zero or near one in the scale-location plot, meaning that there are no large outliers that would cause research bias in the model. The normal Q-Q plot plots a regression between the theoretical residuals of a perfectly homoscedastic model and the actual residuals of the current model. This Q-Q plot is very close, with only a bit of deviation. From these diagnostic plots as shown in Figure 5.2 it can be concluded that the model fits the assumption of homoscedasticity.

An Independent T-Test is performed for the accepted gap of older drivers against MSSQ, and the results are as shown below. When a T-Test is conducted to analyze the accepted gap against the MSSQ score it is seen that the p-value is lesser than 0.05, so the MSSQ score has a real impact on the older driver's accepted gap. The *null hypothesis* H_o is stated as There is no significant difference between the accepted gap value and the MSSQ scores and *alternative hypothesis* H_A is stated as There is a significant difference between the accepted gap value and the MSSQ scores. The results from Table 5.8 show that the alternative hypothesis is accepted in the case of the MSSQ score. When T-Test is conducted for younger drivers to analyze the accepted gap against the MSSQ score it is seen that the p-value is less than 0.05, so the MSSQ score has an impact on the younger driver's accepted gap. The *null hypothesis* H_o is stated as There is no significant difference between the accepted gap value and the MSSQ scores and *alternative hypothesis* H_A is stated as There is a significant difference between the accepted gap value and the MSSQ scores. The results from Table 5.8 show that the alternative hypothesis is accepted in the case of the MSSQ score.

Table 5.8 Accepted Gap of Older and Younger Drivers Vs MSSQ Score

	P-Value
MSSQ Vs Older Driver's Accepted Gap	$3.93971e^{-06\,*}$
MSSQ Vs Younger Driver's Accepted Gap	0.001492023^{*}

The baseline value of EDA and HRV of both young and older drivers was also analyzed by using an independent T-test. These are shown in Table 5.9. The null hypothesis, H_0: There is no significant difference between baseline HRV values of older and younger drivers, and the alternative hypothesis is stated as, H_A: There is a significant difference between baseline HRV values of older and younger drivers, and for EDA The null hypothesis, H_0: There is no significant difference between baseline EDA values of older and younger drivers and the alternative hypothesis is stated as, H_A: There is a significant difference between baseline EDA values of older and younger drivers. As the P-Value is less than 0.05 the null hypothesis is accepted for both EDA and HRV.

Table 5.9 Baseline analysis of EDA and HRV

	P-Value
HRV Young VS HRV Old	0.08913
EDA Young VS EDA Old	0.26272

When T-Test is done for the accepted gap old older drivers and younger drivers against EDA and HRV, the p-value is less than 0.05 for both older and younger drivers in the case of HRV and EDA as shown in Table 5.10. For HRV values against the accepted gap, the *null hypothesis* H_o is stated as There is no significant difference in gap acceptance between HRV values, and *alternative hypothesis* H_A is stated as There is a significant difference in gap acceptance between HRV values. In this case, for both younger and older drivers there is a significant difference between HRV, and the gap acceptance as seen in section 4.3. So, the alternative hypothesis is accepted. For EDA values against the accepted gap, the *null hypothesis* H_o is stated as There is no significant difference in gap acceptance between EDA values, and *alternative hypothesis* H_A is stated as There is a significant difference in gap acceptance between EDA values. In this case, for both younger and older drivers there is a significant difference between EDA and the gap acceptance as seen in section 4.3. So, the alternative hypothesis is accepted.

Table 5.10 EDA and HRV of Young and Old Drivers Vs Gap Accepted

	P-Value
HRV Old Vs Gap Accepted	$6.82e^{-38\,*}$
EDA Old Vs Gap Accepted	$3.64e^{-77\,*}$
HRV Young Vs Gap Accepted	$7.39e^{-51\,*}$
EDA Young Vs Gap Accepted	$1.01e^{-44\,*}$

The red line representing the mean of the residuals is horizontal and centered on zero or near one in the scale-location plot, meaning that there are no large outliers that would cause research bias in the model. The normal Q-Q plot plots a regression between the theoretical residuals of a perfectly homoscedastic model and the actual residuals of the current model. This Q-Q plot is very close, with only a bit of deviation. From these diagnostic plots as shown in Figure 5.3 and Figure 5.4 it can be concluded that the model fits the assumption of homoscedasticity for both the younger and older drivers.

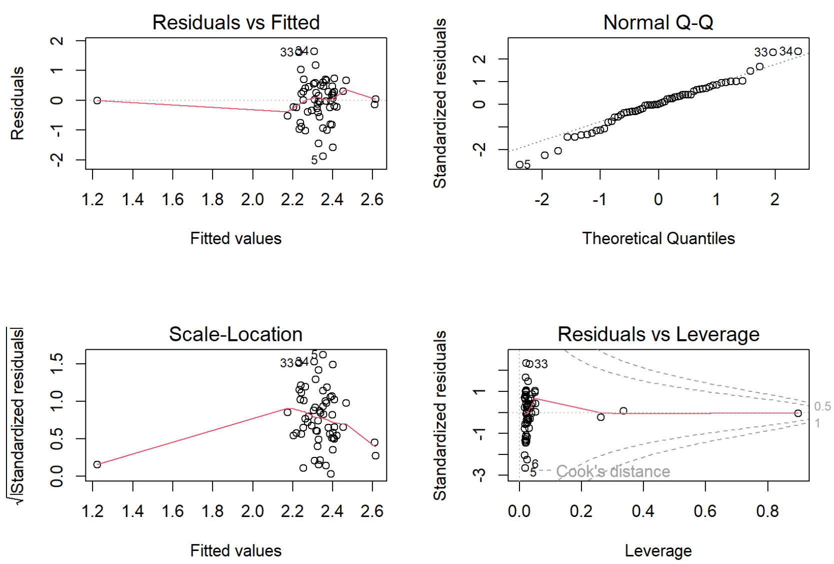


Figure 5.3 Homoscedasticity diagnostic plots for HRV and EDA of older drivers

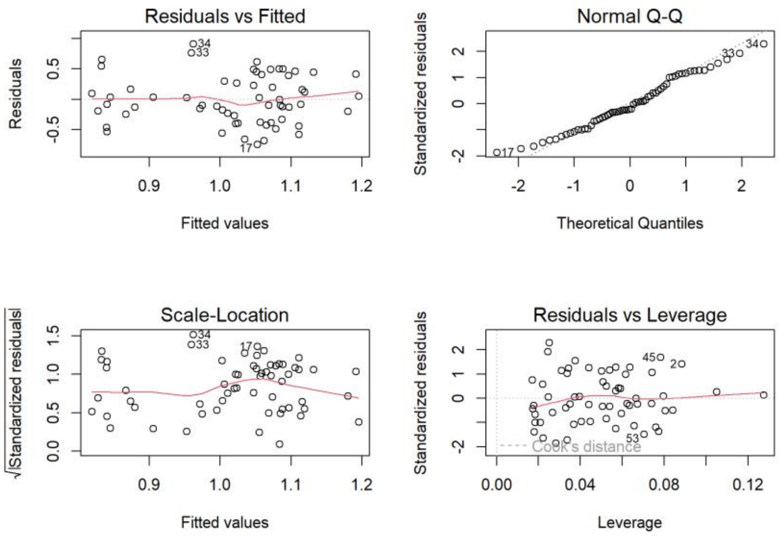


Figure 5.4 Homoscedasticity diagnostic plots for HRV and EDA of younger drivers

Hypothesis testing is done with Pearson test 'r' and the correlation effect is explained by plotting a correlogram. This testing is performed for both older and younger drivers. This can be defined to imply the relationship between the independent variables and the dependent variable. Pearson's r test is done to check whether the accepted gap of both old and young drivers has a significant relationship with EDA, HRV, MSSQ, queue length, traffic volume, and pedestrians in the same way as obtained through exploration of the data. The results of the Pearson test can be seen in Table 5.11 and Table 5.12. From these tables, all the independent variables considered in the experiment against the older drivers and younger drivers' gap acceptance behavior showed a positive correlation.

Table 5.11 Pearson Test for Older drivers

Factor	P-Value	R-Value
Gap Accepted of older driver vs queue length	0.0000001407*	0.3318674
Gap Accepted of older driver vs Traffic Volume	0.00000237*	0.2991691
Gap Accepted of older driver vs Pedestrians	0.01422*	0.09563099
Gap Accepted of older driver vs EDA	0.002267*	0.5599361
Gap Accepted of older driver vs HRV	0.04678*	0.09553658
Gap Accepted of older driver vs MSSQ	0.0000003472*	0.3218213

Table 5.12 Pearson Test for Younger drivers

Factor	P-Value	R-Value
Gap Accepted of younger driver vs queue length	0.0000000001706*	0.483948
Gap Accepted of younger driver vs Traffic Volume	0.0000000005356*	0.3870375
Gap Accepted of younger drivers vs Pedestrians	0.03165*	0.1396364
Gap Accepted of younger driver vs EDA	0.011762*	0.2327261
Gap Accepted of younger driver vs HRV	0.01558*	0.1855509
Gap Accepted of younger driver vs MSSQ	0.00004452*	0.04950965

5.2 Discussion

This study focuses on the queue length, traffic volume, pedestrians, HRV, EDA, and MSSQ score's impact on gap acceptance behavior while taking a left turn at the permissive signalized junction at four-way intersections. From the statistical analysis conducted in section 5.1, the p-value for the accepted gap of older drivers against queue length, Traffic Volume, and Pedestrians are less than 0.05, As the p-value is less than 0.05, queue length, Traffic Volume, and Pedestrians have a significant impact on the gap acceptance behavior of older drivers, and the alternative hypothesis is accepted. For younger drivers, the p-value for the accepted gap against queue length, traffic volume, and pedestrians are less than 0.05. As the p-value is less than 0.05, queue length traffic volume, and pedestrians have a significant impact on the gap acceptance behavior of younger drivers, and the alternative hypothesis is accepted.

When considering 0 queue length, the maximum gap accepted time by the older adults was 5.43 seconds and the minimum gap accepted time was 2.84 seconds, in queue length 1 the maximum gap accepted time by the older adults was 6.17 seconds and the minimum gap accepted time was 2.99 seconds and in queue length 2, the maximum gap accepted time by the older adults was 8.15 seconds and the minimum gap accepted time was 2.86 seconds. When considering 0 queue length, the maximum gap accepted time by the younger drivers was 4.16 seconds and the minimum gap accepted time was 2.05 seconds, in queue length 1 the maximum gap accepted time by the younger drivers was 4.67 seconds and the minimum gap accepted time was 2.03 seconds and in queue length 2, the maximum gap accepted time by the younger drivers was 5.98 seconds and the minimum gap accepted time was 2.05 seconds. When considering higher traffic volume, the maximum gap accepted time by the older adults was 8.15 seconds and the minimum gap accepted time was 2.97 seconds and the maximum gap accepted time by the younger drivers was 5.98 seconds and the minimum gap accepted time was 2.19 seconds. When considering lower traffic volume, the maximum gap accepted time by the older adults was 6.48 seconds and the minimum gap accepted time was 2.84 seconds and the maximum gap accepted time by the younger drivers was 3.99 seconds and the minimum gap accepted time was 2.03 seconds. Older drivers accept longer gaps when exposed to higher traffic volume when compared to younger drivers.

When considering the presence of pedestrians, the maximum gap accepted time by the older adults was 8.15 seconds and the minimum gap accepted time was 3.06 seconds and the maximum gap accepted time by the younger drivers was 5.98 seconds and the minimum gap accepted time was 2.14 seconds. When considering the presence of pedestrians, the maximum gap accepted time by the older adults was 7.97 seconds and the minimum gap accepted time was 2.84 seconds and the maximum gap accepted time by the younger drivers was 4.98 seconds and the minimum gap accepted time was 2.03 seconds. Older drivers accept longer gaps when pedestrians are crossing the road while attempting to take left turns.

At 0 queue length, the older adults at the maximum rejected 4 safe gaps, at 1 queue length they rejected 5 safe gaps and at 2 queue length, they rejected 8 gaps that are safe to make a left turn. On the other hand, at 0 queue length, the younger drivers at the maximum rejected 3 safe gaps, at 1 queue length they rejected 2 safe gaps and at 2 queue length, they rejected 4 gaps that are safe to make a left turn.

At higher traffic volume, the older adults at the maximum rejected 8 safe gaps, and at lower traffic volume, the older adults at the maximum rejected 6 safe gaps. On the other hand, At higher traffic volume, the younger drivers at the maximum rejected 4 safe gaps, and at lower traffic volume, the older adults at the maximum rejected 3 safe gaps. With the presence of pedestrians, the older drivers rejected at the maximum of 8 safe gaps, and younger drivers rejected at the maximum of 4 safe gaps. Without the presence of pedestrians, the older drivers rejected at the maximum of 6 safe gaps, and younger drivers rejected at the maximum of 4 safe gaps.

The interaction effects of the accepted gap of older adults were also analyzed. The interaction between "Traffic: Queue" is 0.00417 which is less than 0.05 this means that there is evidence of a statistically significant interaction effect between the two independent variables on the dependent variable. The interaction between "Queue Length: Traffic Volume: Pedestrians' is 0.01523 which is less than 0.05 this means that there is evidence of a statistically significant interaction effect between the two independent variables on the dependent variable.

The interaction effects of the accepted gap of the younger drivers were also analyzed. The interaction between "Traffic: Queue" is 0.000327 which is less than 0.05 this means that there is evidence of a statistically significant interaction effect between the two independent variables on the dependent variable. The interaction between “Traffic Volume: Pedestrians’ is 0.000117 which is less than 0.05 this means that there is evidence of a statistically significant interaction effect between the two independent variables on the dependent variable. The interaction between “Queue: Pedestrians’ is 0.003152 which is less than 0.05 this means that there is evidence of a statistically significant interaction effect between the two independent variables on the dependent variable.

The interaction effects of the rejected gap of the older adults were also analyzed. The interaction between “Traffic: Pedestrians” is 0.04978 which is less than 0.05 this means that there is evidence of a statistically significant interaction effect between the two independent variables on the dependent variable. The interaction between “Queue: Pedestrians” is $5.7e^{-0.5}$ which is less than 0.05. This means that there is evidence of a statistically significant interaction effect between the two independent variables on the dependent variable. The interaction between “Queue Length: Traffic Volume: Pedestrians’ is 0.00997 which is less than 0.05 this means that there is evidence of a statistically significant interaction effect between the two independent variables on the dependent variable.

The interaction effects of the rejected gap of the younger drivers were also analyzed. The interaction effects between “Traffic: Queue”, “Traffic: Pedestrians”, “Queue: Pedestrians” and ‘Queue Length: Traffic Volume: Pedestrians’. But for all of them, the P-Value is greater than 0.05 so, there is no interaction between the independent variables.

The homoscedasticity diagnostic plots in section 5.1 shows that the red line is horizontal and centered on zero or near one in the scale-location plot, indicating that there are no large outliers that would cause research bias in the model. However, compared to young drivers, these factors tend to impact older drivers more. Younger drivers are affected in a mild amount, as seen from the exploratory analysis in section 4.3.

When considering the baseline EDA and HRV values for both young and old drivers, the p-value is not less than 0.05, so the null hypothesis is accepted, indicating that there is no significant difference between baseline EDA and HRV values for older and younger drivers. From the statistical analysis of the older drivers' gap acceptance against HRV, the p-values are less than 0.05, and the alternative hypothesis is accepted. From the younger drivers' gap acceptance against HRV, the p-values are less than 0.05, and the alternative hypothesis is accepted. From the statistical analysis of the older drivers' gap acceptance against EDA, the p-value is less than 0.05, and the alternative hypothesis is accepted. From the younger drivers' gap acceptance against EDA, the p-value is less than 0.05, and the null hypothesis is rejected.

Chapter 6

Conclusion

This study was conducted with both young and older drivers, and the results demonstrate the factors and their impact on the gap acceptance behavior of these drivers in four-way intersection left turns. Physiological factors used in this study, such as EDA and HRV, were collected through the E4 Empatica Wristband during the simulator study, which involved driving in different scenarios with high and low traffic, with and without pedestrians, and with one, two, and three queue lengths. The participants were also asked to fill out questionnaires before and after the experiment.

When queue length, traffic volume, and pedestrians were analyzed for young and elderly adults, all three factors were statistically significant in the results of ANOVA, as seen in section 5.1. Queue length, traffic volume, and pedestrians have a greater impact on the accepted gap length of older drivers when compared to younger drivers, as seen in the exploratory analysis in section 4.3. For both age groups, the model became better by adding traffic volume and pedestrians, as evidenced by showing less residual in each step. As the queue length and traffic volume increase, the accepted gap increases for both age groups, but it has a greater effect on the older drivers compared to the younger drivers. When pedestrians are crossing, older adults tend to take a longer gap compared to scenarios where there were no pedestrians. However, when considering the interaction effect, there is not much variation that can be explained, as the sum of squares is lower with a higher p-value.

The HRV and EDA values had a positive correlation, but in the exploratory analysis conducted in chapter 4, the EDA remained the same when taking left turn and while waiting for both younger and older adults. As the heart rate variability increases, the accepted gap time also increases and decreases with the decrease in heart rate variability for older adults. The heart rate variability did not have impact on younger drivers when compared to older drivers. The MSSQ score has an impact on the accepted gap length for older drivers and younger drivers as the MSSQ score increases, the accepted gap also increases during exploratory analysis (section 4.3).

At 0 queue length, the older adults at the maximum rejected 4 safe gaps, at 1 queue length they rejected 5 safe gaps and at 2 queue length, they rejected 8 gaps that are safe to make a left turn. On the other hand, at 0 queue length, the younger drivers at the maximum rejected 3 safe gaps, at

1 queue length they rejected 2 safe gaps and at 2 queue length, they rejected 4 gaps that are safe to make a left turn.

At higher traffic volume, the older adults at the maximum rejected 8 safe gaps, and at lower traffic volume, the older adults at the maximum rejected 6 safe gaps. On the other hand, At higher traffic volume, the younger drivers at the maximum rejected 4 safe gaps, and at lower traffic volume, the older adults at the maximum rejected 3 safe gaps. With the presence of pedestrians, the older drivers rejected at the maximum of 8 safe gaps, and younger drivers rejected at the maximum of 4 safe gaps. Without the presence of pedestrians, the older drivers rejected at the maximum of 6 safe gaps, and younger drivers rejected at the maximum of 4 safe gaps. Hence older adults reject more amount of gap when compared to the younger drivers and tend to accepted longer gap also.

The insights obtained through this work will be of great consideration while analyzing the factors that cause some drivers to take longer to take a left turn.

6.1 Limitations

Limitations of this lab-based study include the fact that it does not provide a real-world uncontrolled situation. The concept of a monitored simulator experiment is likely to affect the driver's performance along with the use of wearable sensors when compared to a naturalistic study [73, 76]. For example, during the practice trials, many participants initially reported that the Logitech G29 steering wheel and pedals had a different feel from the vehicles that they used to drive. Even the acceleration in the CARLA driving simulator did not reciprocate actual vehicle acceleration as the speed would rapidly drop to zero if the foot was taken off the accelerator pedal, which meant the participants had to apply some extra effort to maintain their speed. They also faced similar problems when they wanted to slow down the speed of the vehicle. Although there have been previous studies done in simulators for left-turn gap analysis, there will always be a difference in driver behavior in the simulator when compared with the on-road environment [75]. Additionally, one old-aged driver felt motion sickness when they were driving during the practice sessions, and three other drivers felt tired and wanted to discontinue the experiment in the middle of the original driving session.

The window of the experiment was limited to 2 minutes, and the duration may be very short to observe any significant changes. To observe and analyze the factors more accurately, it would be necessary to increase the scenario time and conduct the study as a naturalistic driving study. In the real world, drivers may be exposed to many different driving conditions like night-time driving, snow driving, or unpaved road driving situations. Therefore, the observations and findings discussed in this thesis cannot be generalized. These observations may also vary and rely on the instrument or sensor that we use to collect data since it determines the quality of the data that is being analyzed. For example, some older participants may be new to driving simulators and become nervous, resulting in an increased heart rate and being prone to motion sickness, whereas younger drivers are more exposed to simulators by playing more video games and are not prone to any kind of motion sickness or nervousness, which may lead to biases in the results. Additionally, the experimenter used only one monitor for the experiment, which might have limited the participants' perception. However, these simulators help to create more complex road situations, which is not possible in the real-world driving environment [77].

Another limitation was that the sample was not completely randomized as the study was advertised and conducted at the university. It restricted the younger participant pool mostly belonging to the university students, and the older participant pool was also given by the university's aging research community.

6.2 Future Work

The insights obtained from this study can be considered when analyzing the gap acceptance behavior at four-way intersections for both young and elderly drivers taking left turns. However, in the future, these insights can be improved by developing technologies to assist older drivers with gap acceptance behavior. New technologies, such as advanced driver assistance systems (ADAS), could be developed to provide real-time feedback and warnings to drivers when they attempt to enter a gap that is too small or when there is a high risk of a collision.

While driving, many drivers may be distracted by music, radio, cellphone calls, or disturbed by co-passengers. These factors may also be considered when analyzing gap acceptance. In real-world driving, drivers may be exhausted and end up driving rashly or feel drowsy while driving [78-83][88]. Weather conditions, such as rain or snow, surface conditions such as wet, icy, or snowy, and strong winds, fog, or storms could also affect gap acceptance behavior [84,85]. A comparative study could also be conducted between signalized and un-signalized intersections [86] [89-91].

Furthermore, the experiment could be conducted in the real world by combining new factors such as weather conditions, distractions, and drowsiness along with the factors used in this study.

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Appendix A

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