An Examination of Drivers' Responses to Take-over Requests with Different Warning Systems During Conditional Automated Driving

by

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Abstract

Today, the autonomous vehicle industry is growing at a fast pace towards Level-5 autonomous cars, based on the Society of Automotive Engineers (SAE) definition, for customers. It is expected that there will soon be SAE Level-3 automated cars in the market – which corresponds to a plethora of research works in this sector and one of them is the study of the design of takeover request warning system because failure to respond a takeover request warning may lead to fatal accidents. The objective of this study is to examine the effects of different warning types on drivers' takeover responses while they are engaging in different non-driving tasks during conditional automated driving. This study is a simulator-based with a mixed-subjects design while participants interacting with a simulated Level-3 automation system under different conditions. A total of 24 participants were recruited and participated in the study. Each participant experienced two types of takeover request (TOR) warning systems (Auditory TOR and Multimodal TOR) under four types of non-driving task conditions with two levels of non-driving task duration. One baseline drive without any secondary task was also designed for comparison with those conditions with non-driving tasks. Three research questions are addressed in this thesis:

- Will a Multimodal TOR lead to better driver responses in reaction to takeover requests than Auditory TOR?
- Will the different type of non-driving tasks lead to different cognitive engagement of drivers, therefore resulting in different reactions to takeover requests?

- Will different duration of engagement in non-driving tasks impact on responses of drivers' re-engagement in driving tasks?

In this study, data was collected for both objective driver measures through simulator run log files and subjective driver measures through questionnaires. For analysis purposes, a Mixed-Effects Model was conducted to test the response variables, followed by the Fisher LSD Pairwise Comparison test for significant factors with more than two levels and Two-Sample t-tests for subjective measures were used. Results showed that Multimodal TOR leads to shorter brake time and steer touching time comparatively and the difference of these dependent variables between the TORs is significant as p-value<0.05. The findings also suggest that the Multimodal TOR warning system leads to a better reaction of drivers. Moreover, it was also found that the type of non-driving tasks leads to different driver responses, more specifically, drivers have a significantly slower reaction towards the takeover request if they are engaging in visual-manual non-driving tasks when compared to if they are engaging in other types of non-driving tasks (e.g., cognitive or visual tasks). However, there are no significant gender-based effects observed for Brake Time and Steer Touch Time.

Chapter 1 Introduction

The current automobile market has up to Level-2 automated cars available to the customers for buying. As per National Highway Traffic Safety Administration (NHTSA) and SAE Taxonomy [1], Level-2 automated vehicle is defined as vehicles with – combined automated functions which can perform two primary control functions at the same time. In conditional automated driving (Level-3 Automation: Limited self-driving automation – the driver may hand over full control of all safety-critical vehicle functions under certain conditions but is expected to be available for occasional control; as per NHTSA-2013 United States [1]), the car drives itself for most of the time, but the driver must intervene when the automation provides a takeover request (TOR) under certain conditions that the automation cannot handle. Human factors research in the SAE Level-3 technology development is critical as there is a great need for understanding how to design the warning system so drivers can re-engage in the driving situation loop from non-driving tasks and be ready to take over the vehicle control within a short period. [2]

What happens when a driver is inattentive during the time of a takeover request? What happens if a driver is not in the control loop after a period of passive monitoring during a takeover request? In layman terms, the answer is straightforward – this increases the chances of potential fatality to the driver, the car straight ahead, the pedestrian and other road users [2]. There have been several automated vehicle-related collision cases such as there was one accident in which Tesla Model S' autopilot reached its system limits and collided with a parked police car

[3]. In another case, an Uber test vehicle (Volvo XC-90) failed to recognize a pedestrian crossing and killed the pedestrian, and the vehicle operator was also injured [4]. These collision cases indicate that drivers may over trust in the car automation system. They failed to understand the system limits of car automation and as a result, became inattentive and lost awareness of the surroundings. Inattentiveness and loss of situational awareness may occur due to – talking to passengers, calling on the phone, texting on phone, eating food, surfing online via smartphones and so on. There is a great research need for studying the effect of these non-driving tasks on drivers' responses to takeover request warning conditions to avoid a potential collision.

Background Studies

There had been a plethora of research studies conducted by human factors researchers. In one of the studies [2], the objective was to investigate the reaction times, correct response rate, eye, and head movements towards two types of vibrotactile takeover warning systems. In their study, the vibration warnings from the seat pan gave out directional cues through dynamics (whether to switch to the left lane or right lane) to the participants, while in the second type of vibration warnings in the study were static, which also presented the directional cues. In the latter one, the directional cues were conveyed by turning ON either the left side motors or right side motors on the seat pan, while in the former one, the directional cues were offered by turning ON the motors either from left to right side or from right to left side in the seat pan. In the study, the participants experienced three conditions – Baseline (no driving) in which they were only required to comment the directional cue; Driving a conditionally automated car with no additional task in which they had to switch lanes as per the directional cue offered to them via the takeover warning system, and Driving a conditionally automated car with N-Back task in which they had to switch lanes as per the directional cue presented to them via the takeover warning system. After the experiment, the authors concluded that vibrotactile stimuli are effective as takeover request warning systems and can bring back the drivers into the control loop. Despite its effectiveness as a takeover warning system, the vibrotactile seat is comparatively less effective from the perspective of directional cues that were offered from static as well as dynamic vibrations in the driver seat. The major trade-off that was observed related to the directional cue was that no matter the directional cue offered to the participants, they always chose to overtake the vehicle ahead from the left lane (high-speed lane) which goes with the fact that while driving a left-handed car, it is always advisable to overtake from the left lane (or high-speed lane) as per the traffic rules.

In another study [5], the researchers studied the effects of takeover request modality and left/right directionality of the takeover request warning system on driver's steering behavior for the takeover under a critical situation of a potential crash with the leading vehicle. In this study, there were no instructions passed to the participants regarding the directional cues of the takeover warning system. Participants performed three driving sessions on a conditionally automated car in which they received three different takeover request modality – auditory, vibrotactile and combination of both (multimodal). In total, a participant was presented with six takeover requests per session, consisting of – two coming from the left, two coming from the right while two were non-directional (coming from both sides). Speakers were used for the generation of an auditory stimulus (left, right or both side speakers) while vibrotactile seats with motors, activated at the left side, right side and both sides were used for generating vibrations in the seat. The researchers found out that for the multimodal takeover request warning system, the participants reacted quickly and efficiently towards the takeover condition. While for the directionality of the takeover request warning system perspective, the results were not significant as it was found that participants used the left lane irrespective of the directional cues that were offered to them, which goes in-line with [2].

For testing the reaction times of the drivers towards the takeover request warning, some researchers took a different approach. That approach consisted of providing a certain amount of buffer time (time between the generation of the takeover request and time to reach the crash or near-crash event when the automation was turned on) to the participants. In one of the studies [6], the researchers set a buffer time of 10 seconds and observed if the participants were able to react effectively and efficiently towards a takeover request warning while they were engaged in a non-driving task (playing a challenging quiz game on phone). The takeover warning system consisted of different strategies – a phone or in-vehicle HMI integrated visual icon was used; inducing variation in takeover request warning system by integrating and disintegrating brake jerk. They found that all participants were able to react within 10 seconds with a mean reaction time of 6.5 seconds. However, the type of warning system did not affect the reaction time. This was because participants already knew about the buffer time of 10 seconds for reacting towards the takeover request warning system. In another study [7], the researchers considered three types of transition time conditions (takeover time condition – defined as an abrupt failure in control of car automation system) – two seconds, five seconds and eight seconds when the car entered a curve from a straight road. Plus, they also included a distraction task on the tablet which was not compulsory for the participants to engage in during the experiment. They found that majority of the drivers were able to navigate the hazard situation when they had a buffer time of between five seconds and eight seconds.

For a successful takeover, another important factor in addition to the type of non-driving tasks is the duration of engagement in a non-driving task. In a study [8], the researchers investigated that the engagement duration of the secondary task or non-driving task that distracts the driver is a contributing factor to motor vehicle accidents among adults. They collected data from 42 newly licensed teenagers for 18 months by setting up cameras, accelerometers and Global Positioning System (GPS) in their cars. For every Crash and Near crash event, the video footage of six seconds before the event was taken into consideration for monitoring the participants' eye glance behavior. They studied three hypothesis – Risk increases with each additional second of the single longest eye glances off the roadway (LGOR) (>1 s, >2, >3, >4, and >5 s); Risk increases with each additional second of total duration of eye glances off the roadway (TEOR) (>1 s, >2, >3, >4, and >5 s); Risk is greater for LGOR and TEOR related to wireless compared with all secondary tasks. They found that the longer duration of eyes-off the road increased the chances of a crash, irrespective of the type of secondary task or non-driving task in which the participants were engaged in before reaching the crash and near-crash event.

Research Gap

The main problem associated with the increased level in automation is that there is a delay in drivers' responses to critical situations due to reduced driver vigilance such as increased braking reaction time and steering reaction time [7]. In the domain of conditionally automated driving (CAD), this reduced vigilance and inattention may pose problems for drivers who are required to manually intervene during critical automation failures, which can be very demanding for a driver that he/she may have difficulty dealing with it, and end up with potential crashes. [9].

Research Questions, Objectives and Hypotheses

Referring to the above-mentioned problems, previous studies suggest that drivers may be more vulnerable to distractions, secondary tasks or non-driving tasks (e.g. calling and texting on cell phones more frequently, conversing with fellow passengers or surfing media in their cell phones) during periods of Conditionally Automated Driving (CAD) in comparison to Level-2 and Level-1 automated driving. Drivers' engagement in non-driving tasks can lead to reduced situational awareness of driving which can pose a critical safety issue by compromising the ability of the driver to suddenly regain control of the vehicle when required. [10] It is evident that there is a great need to study the effect of different non-driving tasks and the effect of different warning types on the reaction time of a driver during CAD with a takeover request process. This will help to understand drivers' cognitive load during the process and therefore to develop a model taking the non-driving tasks and warning types into account in the design to – avoid a collision and/or severe accident with the car straight ahead, with the pedestrian and other road users.

The research questions that were addressed in this study are as follows:

- Will a Multimodal TOR lead to better driver responses in reaction to takeover requests than Auditory TOR?
- Will the different types of non-driving tasks lead to different cognitive engagement of drivers, therefore resulting in different reactions to takeover requests?
- Will different duration of engagement in non-driving tasks impact on responses of drivers' re-engagement in driving tasks?

To answer these questions, the aim of the study was formulated, which was – "to examine the effects of different warning types on drivers' takeover responses while they are engaging in different non-driving tasks during conditional automated driving". The hypotheses of this study were summarized and as follows:

- The reaction time of takeover requests will be longer when a driver is performing visual-manual tasks in comparison to other non-driving tasks.
- For a non-driving task, longer duration of engagement will lead to longer reaction times to takeover requests.
- "Multimodal" warnings can lead to better or faster responses and shorter reaction times in comparison to "Auditory" warnings.
- There will be individual differences in the responses to the takeover request warning.

Chapter 2 Methods

The present study is a simulator-based experiment that was conducted at the University of Michigan-Dearborn Driving Simulator lab. It is a fixed base driving simulator in which the car buck is fixed at one place during the entire course of the study. The driving scenario is displayed in the projector screen with a 147-inch-wide display having a 74 degrees horizontal and 21 degrees vertical field of view from an 89 inch (plus/minus seat adjustment) viewing distance. Moreover, it has an inside rear-view mirror which gives a display of rear traffic to the driver.

Apparatus

The entire lab arrangement for the study is shown in Figure 2-1. The simulator has a steering wheel, gas pedal, brake pedal and a gear shifter consisting of three modes – neutral, drive and reverse. Also, there are two paddle shifters attached with the steering wheel which, when pulled together, turns on the Conditional Automated Driving (CAD) mode of the simulator. Numeric data is collected in the simulator at a rate of 60 Hz and subjective data is collected using some questionnaires. Plus, video data is also collected using the GoPro Hero5 device which is set to record video at a resolution of 1080p and a frequency of 60 Hz.

Figure 2-1 Driving Simulator Lab depicting GoPro device, Instrument Cluster of CAD system, Infotainment Screen and Driving Scenario on the Projector Screen

Figure 2-2 Car Buck depicting Gear Shifter, Infotainment Screen and Driving Scenario

Figure 2-3 A zoomed-in view of the Car Buck to depict Paddle Shifters in between Steering wheel and Instrument Cluster for activating CAD System

Driving Scenario and Takeover Critical Situations

Two city scenarios were constructed using SimVista and SimCreator software which has a speed limit of 35 mph, traffic signals, four-lane roads, four-way intersections and three-way intersections with software-generated default vehicle traffic which gets a reset after every run of the scenario mapping. One driving scenario (termed as Baseline Drive) is, on average, 3-4 minutes long in which the participant had to respond towards the TOR warning system two times and was asked not to engage in any of the non-driving tasks (NDT). While, the other driving scenario (termed as NDT Drive) is, on an average, 23-24 minutes long in which the participant had to respond towards TOR warning system 12 times (3 NDT types * 2 NDT duration * 2 Warning types) and was also asked to engage in NDT as per researcher's instructions during the course when CAD system was turned ON or active. The order of Baseline drive and NDT drive were counterbalanced. Critical Situations were designed under which sensors were not working appropriately and drivers are required to take over the car controls. It is worthy of pointing out that the design of the two critical situations in this study may not reflect the real sensor failure situations, rather a simulated takeover process. The two types of critical situations that were designed in the study are as follows:

- Potential Jaywalking – In this critical situation, a pedestrian tries to jaywalk suddenly when the subject car is near, and the driver has to takeover to maneuver the situation in a safe, effective and efficient manner.

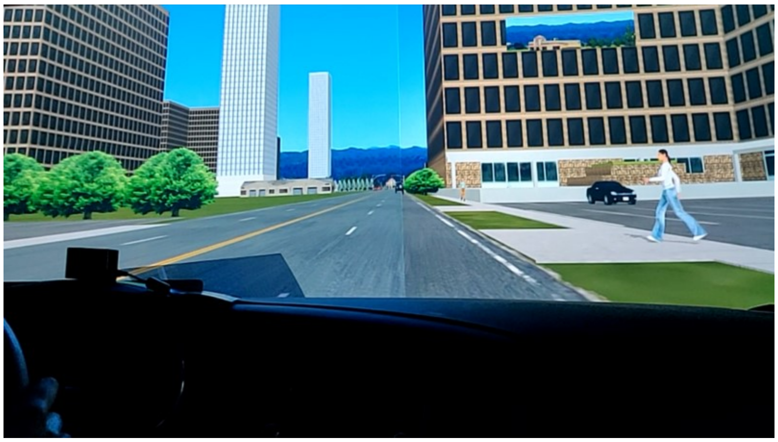

Figure 2-4 Showing the "Potential Jaywalking" Critical Situation

- Car Pulling out of Parking – In this critical situation, a car pulls out from the parking to the main road at high speed and the driver is expected to takeover to maneuver the situation in a safe, effective and efficient manner.

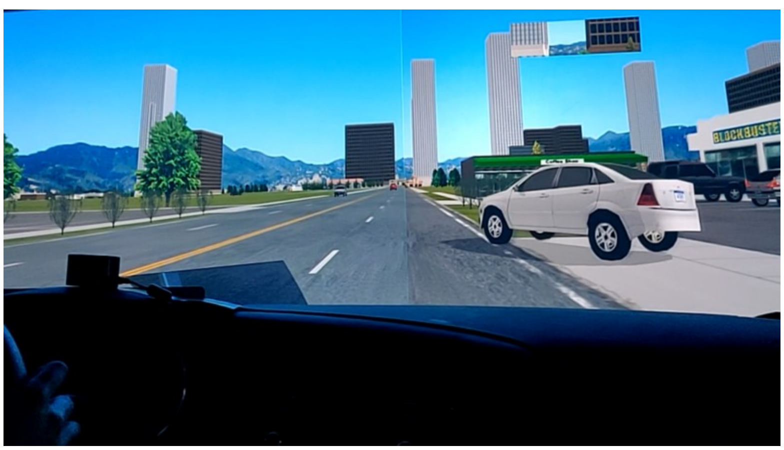

Figure 2-5 Showing "Car Pullout from Parking" Critical Situation

Takeover Request Warning Types

In this study, two types of TOR warning systems were developed and examined. Both objective and subjective driver responses were collected under the two critical situations. The warnings were issued when drivers were seven seconds away from the critical situation site so that the driver had a buffer time of seven seconds to react towards TOR warning and manage the critical situation. The seven seconds selection was based on other studies' findings [6-8], in which the researchers found that irrespective of buffer time or takeover transition time provided to the drivers for taking over, it was observed that on average, a driver was able to react effectively to the takeover warning between a time frame of five seconds to eight seconds.

TOR should be designed in such a way that – the driver does not panic upon its reception and should contain some sort of instruction for the effective and efficient takeover request process. Keeping these principles in mind, both TORs were developed and tested:

- Auditory TOR warnings: It is mostly chimes based and have been introduced in previous studies [5] and is already installed in the level-2 cars. In this study, the auditory TOR is designed to include semantic audio instructions which are simple sentences that not only alerts the driver about the critical situation but also gives information about that critical situation.
- Multimodal TOR warnings: From previous studies [5], it mostly contained two modes only – either audio and vibrations or audio and a visual icon. In this study, the Multimodal TOR warnings contain three modes. The driver receives a takeover request warning regarding the critical situation through three channels: semantic audio, vibrations on the driver seat and a visual icon along with text in the instrument cluster.

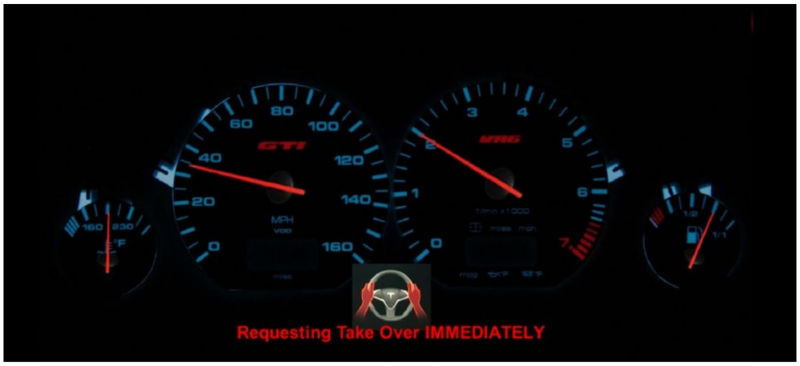

Figure 2-6 Showing the Visual Icon and Text for Multimodal TOR

Figure 2-7 Showing the icon when the CAD system is activated or turned ON or engaged

Figure 2-8 Vibrotactile Mode of the Multimodal TOR

Non-Driving Tasks (NDT)

As mentioned earlier, drivers were asked to engage in a set of NDTs when the automated driving mode of the CAD system was turned ON or active. For this study, all participants were asked to engage in four different types of NDT. They are summarized as follows:

- Surfing the Internet on the Phone – This is a visual manual task as participants are required to operate the phone with their hands and at the same time having to keep their eyes on the phone screen.
- Watching a Video on Infotainment Screen – This is a visual task in which participants play and watch a video clip on the in-vehicle infotainment screen.
- Oral Math Questions – This is a cognitive task in which the participants answer some oral math questions to the researcher without using their phone or calculator.
- Baseline – To examine the NDT effect, a baseline drive was also designed in the study in which the participant was asked not to engage in other non-driving tasks when the CAD system was active.

Procedure

After setting up the lab for human-subjects data collection, for gathering participants, the flyers of this study were put up on the university notice boards, sent to the university's Facebook group and other student organization groups. The participants reached out to the Principal Investigator (PI) through email or phone for enquiring regarding the study. After that, the PI emailed the information about the study to them and a tentative agreement of their participation was finalized over email. When participants arrived at the University of Michigan-Dearborn Driving Simulator lab. He/she would be given a brief introduction of the purpose of the research study and was asked for his/her consent of participation on a Consent Form followed by a Pre-Drive Questionnaire to collect some driving knowledge data and demographics data of the participant. He/she was then asked to sit on the driver seat of the simulator and was instructed about the controls of the car buck, driving scenarios, TOR warning systems, NDT and other subjective documents that were to be filled during and after the experimental drives. The participant was given a trial drive to get accustomed to the vehicle controls and CAD system of the simulator. Once he/she was comfortable with the simulator drive, both experimental drives were followed, and driving measures and video data were collected. The order of the experimental drives, NDT type, NDT duration of engagement and TOR warning type were randomized among the participants. The job for the participant was almost the same for both Baseline Drive and NDT Drive with the only exception being the engagement in non-driving tasks in NDT Drive as oppose to Baseline Drive in which he/she was just required to sit idle when the CAD system was active. Upon the starting of the drives, he/she had to drive until there was an auditory instruction from the car buck saying to TURN ON the automation system. He/she had to pull both the paddle shifters on the steering wheel for engaging automation and once the CAD system was active, he/she was instructed to remove his/her hands from the steering wheel and feet from the pedals. However, during critical situations, the participant took control of the car by pressing the brake to TURN OFF the CAD system and maneuver the situation. He/she was then required to drive for some time until there was another auditory instruction from the car buck saying to TURN ON the automation system. After the end of each drive, the participant was given a NASA-TLX form to assess the task load during the drive. In the end, he/she answered the Post Drive Questionnaire and was handed over his/her compensation for his/her participation. The whole experiment took about one hour of each participant's time.

Experimental Design and Statistical Analysis

This study employs a Mixed-subject design consisting of 24 participants with a 50-50 gender ratio. The range of the participant's age is between 18 years old and 30 years old (Mean = 21.13 years and Standard Deviation = 2.54 years). All participants were required to have a valid driver's license. They were compensated with $30 for their participation time in the study.

The independent variables that were used in the analysis include:

- Non-driving task type – 4 levels (Surfing the internet on phone, Watching a video on the infotainment screen, Oral Math questions, Baseline).
- Non-driving task duration of engagement – 2 levels (60 seconds, 10 seconds).
- Takeover Request (TOR) Warning type – 2 levels (Auditory TOR, Multimodal TOR).
- Gender – 2 levels (Male, Female).

The dependent variables that were used in the experiment include:

- Brake Time – Time taken by the participant to press the brake pedal upon receiving the takeover request warning. This driver performance measure is obtained directly from the simulator run log files.
- Steer Touch Time – Time taken by the participant to grip the steering wheel (either one hand grip or two hands grip) upon receiving the takeover request warning. This driver performance measure is also obtained directly from the simulator run log files.

- Drivers' Subjective Ratings – These are subjective ratings that are taken from the participants via Post Drive Questionnaire and NASA Task Load Index.

For objective driver measures data analysis, first, the data were tested for normality. Anderson-Darling Normality test was conducted on all the dependent variables and it was found that the p-value for all the responses was less than the significant level, concluding that the data does not follow the normal distribution. After that, a Mixed Effects Model was conducted for Brake Time, Steer Touch Time and Standard Deviation of Steer Turn to check the significance of independent variables and their interactions. This was followed by the Fisher LSD Pairwise Comparison of significant factors with more than two levels. Moreover, a two-sample t-test was conducted to analyze the subjective measures. All statistical analysis methods were carried out in the Minitab software.

Calculation Method for Objective Dependent Variables

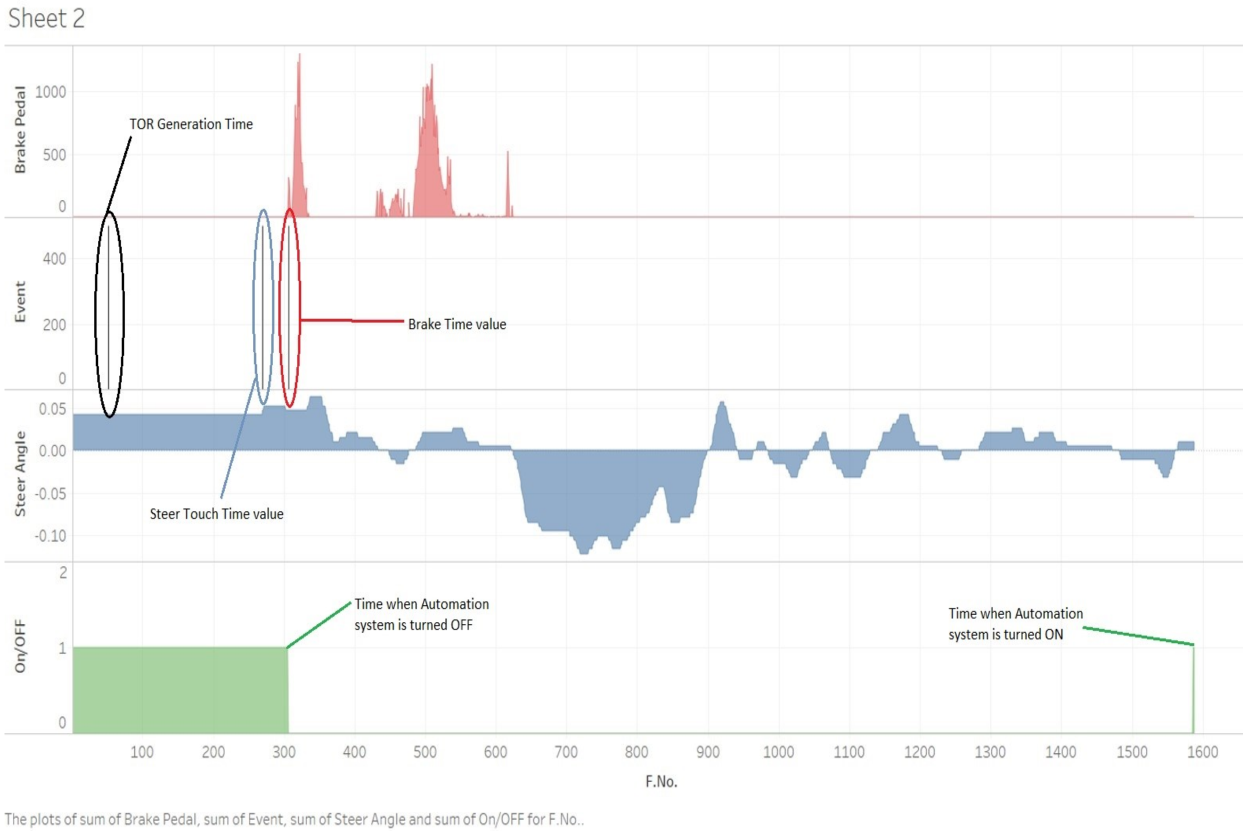

Figure 2-9 A small-time chunk of a participant showing (from top to bottom) Brake Pedal values, Events, Steer Angle Values and ON/OFF state of the CAD system

Figure 2-9 depicts the graph of the calculation of Brake Pedal (in red color), Event (shown by black vertical lines), Steer Angle (in blue color) and Automation ON/OFF (in green color). The horizontal axis shows the frame numbers of the time chunks.

In the Brake Pedal graph, it can be observed that the value of the brake pedal is zero when the automation is turned ON or is active. In the Steer Angle graph, it can be observed that the value of the steering angle is constant when the CAD system is active as the participant was instructed not to touch the steering wheel during the conditional automated driving. Moreover, the Automation ON/OFF graph is at a constant value of one during the conditional automated driving and zero when it is turned OFF.

There are three events shown in the Event graph that is used for the calculation of dependent variables. The first vertical line shows the frame number or time at which the takeover request warning is generated. The second line shows the frame number or time at which the participant touches the steering wheel for the first time after receiving the takeover request warning which can also be seen by a slight variation in the steering angle. The third line shows the frame number or time at which the participant presses the brake pedal, to turn OFF the CAD, for the first time after receiving the takeover request warning. Each vertical line has a certain amount of time value or frame number associated with it.

Let,

Time value when takeover warning is generated be W seconds

Time value when the steering wheel is touched for the first time after receiving TOR be S seconds

Time value when the brake pedal is pressed for the first time after receiving TOR be B seconds

Brake Time = $(B\ seconds - W\ seconds)$

Equation 1 Brake Time Calculation

Steer Touch Time = $(S\ seconds - W\ seconds)$

Equation 2 Steer Touch Time Calculation

For calculating Standard Deviation of Steer Angle, it is calculated using the equation of sample standard deviation from the time value when the steer touch occurs until the time value when the participant turns ON the CAD system.

Mean Steer Turn = Xbar = $\left(\frac{\sum_{i=S}^{i=N} Xi}{N}\right)$

Equation 3 Mean Steer Turn Calculation

Standard Deviation of Steer Turn = s = $\sqrt{\{[\sum_{i=S}^{i=N}(Xi - Xbar)^2]/[N-1]\}}$

Equation 4 Standard Deviation of Steering wheel Calculation

Where,

N = Sample of Observations (from S second until Frame number when the CAD system turns ON)

Xi = ith Value of the Steer Turn

Xbar = Mean value of the Steer Turn for N observations

s = Sample Standard Deviation of Steer Turn

Chapter 3 Results and Discussion

Mixed-Effects Model

For the analysis purpose, firstly, a Mixed-Effects Model was done on the dataset to identify the significant independent variables for each dependent variable. This was followed by a Fisher LSD Pairwise Comparison for significant variables, with more than two levels, for each dependent variable. This analysis was conducted using Minitab and the variance estimation method used is Restricted Maximum Likelihood. It had two cases, firstly, including Baseline drive data (to examine whether NDT leads to reduced driver responses when compared to attentive driving) and the second set of analyses focuses on understanding the impact of duration and type of NDT on drivers' responses to TOR by using only NDT driving data (i.e., excluding baseline drive data).

Case-1: Mixed-Effects Model of Dependent Variables including Baseline

Table 3-1 gives information about the factors or independent variables for the mixed-effects models.

Table 3-1 Factor Information for Mixed Effects Model Including Baseline

Factor	Type	Levels	Values
Gender	Fixed	2	Female, Male
I.D.(Gender)	Random	24	F1(Female), F10(Female), F11(Female), F12(Female), F2(Female), F3(Female), F4(Female), F5(Female), F6(Female), F7(Female), F8(Female), F9(Female), M1(Male), M10(Male), M11(Male), M12(Male), M2(Male), M3(Male), M4(Male), M5(Male), M6(Male), M7(Male), M8(Male), M9(Male)
Warning Type	Fixed	2	Auditory, Multimodal
NDT type	Fixed	4	Baseline, Internet, Math, Video

The analysis result for Brake Time is summarized in Table 3-2. For the fixed factor effects, only the Warning type and NDT type (both highlighted in red) showed significant effects on drivers' brake reaction time (p-value is less than 0.05). Table 3-3 shows the least square means for both significant factors. The mean Brake Time for Auditory TOR warning is greater than the mean Brake Time for Multimodal TOR warning, indicating that the latter is a significantly better TOR warning system than the former as it gives faster response values.

Moreover, for NDT type, the mean Brake Time for Baseline NDT type was surprisingly greater than other NDT types (Figure 3-2). This result goes against the research hypothesis. However, the possible explanation for this result can be that it is difficult to control the cognitive state of the participants experiencing Baseline Drive which may have affected their reaction time towards the takeover request warning system.

Table 3-2 Test of Fixed Effects for Mixed Effects Model for Brake Time

Term	DF Num	DF Den	F-Value	P-Value
Gender	1.00	22.00	2.12	0.160
Warning Type	1.00	88.00	28.32	0.000
NDT type	3.00	66.00	4.39	0.007
Gender*Warning Type	1.00	88.00	0.49	0.484
Gender*NDT type	3.00	66.00	0.80	0.497
Warning Type*NDT type	3.00	88.00	2.62	0.056
Gender*Warning Type*NDT type	3.00	88.00	1.63	0.188

Table 3-3 Conditional Means of Significant Factors for Mixed Effects Model for Brake Time

Term	Fitted Mean	SE Mean	DF	T-Value	P-Value
Warning Type					
Auditory	2.83411	0.101686	29.701	27.87	0.000
Multimodal	2.42587	0.101686	29.701	23.86	0.000
NDT type					
Baseline	2.86736	0.131265	64.060	21.84	0.000
Internet	2.76648	0.131265	64.060	21.08	0.000
Math	2.41094	0.131265	64.060	18.37	0.000
Video	2.47518	0.131265	64.060	18.86	0.000

Table 3-4 Fisher Individual Tests for Differences of Mean Brake Time for NDT type

Difference of NDT type Levels	Difference of Means	SE of Difference	DF	Individual 95% CI	T-Value	P-Value
Internet - Baseline	-0.101	0.149	66	(-0.399, 0.197)	-0.68	0.502
Math - Baseline	-0.456	0.149	66	(-0.755, -0.158)	-3.06	0.003
Video - Baseline	-0.392	0.149	66	(-0.690, -0.094)	-2.63	0.011
Math - Internet	-0.356	0.149	66	(-0.654, -0.057)	-2.38	0.020
Video - Internet	-0.291	0.149	66	(-0.589, 0.007)	-1.95	0.055
Video - Math	0.064	0.149	66	(-0.234, 0.362)	0.43	0.668

A Fisher LSD Pairwise Comparison test was carried to analyze the impact of NDT type on the Brake Time. Table 3-4 shows the significant pairs (highlighted in red), which is also confirmed from Figure 3-1 as well.

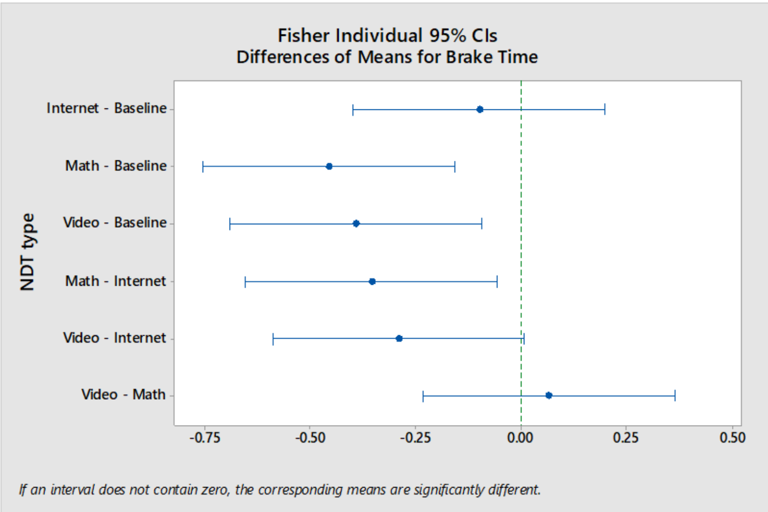

Figure 3-1 Differences of Means for Brake Time

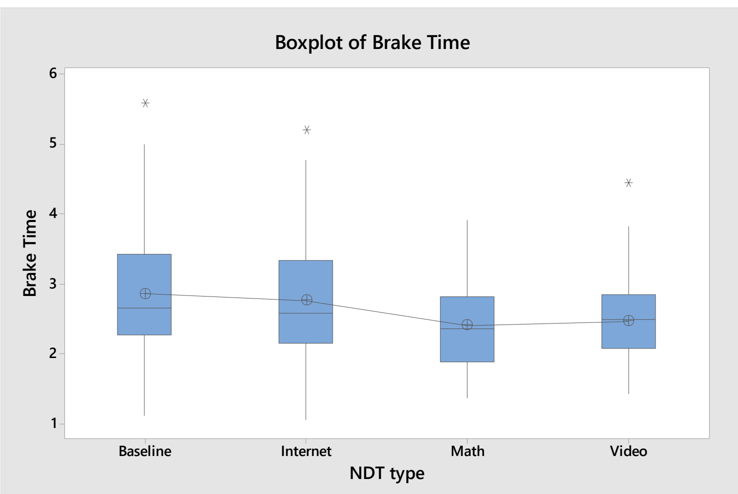

Figure 3-2 Boxplot comparing Brake Time of NDT type

Results of the Mixed-Effects Model for Steer Touch Time are as under. From Table 3-5, it can be observed that the Warning type and NDT type are the two fixed factors that impact the Steer Touch Time significantly as they have a p-value less than 0.05. Moreover, from Table 3-6, it can be noted that the mean Steer Touch Time for Surfing the Internet NDT type is greatest among all other mean Steer Touch Times (Figure 3-4). This proves the first hypothesis that it takes a longer time for the drivers to react when they are engaged in a visual manual non-driving task in comparison to other tasks. Moreover, the mean Steer Touch Time of Auditory TOR warning is significantly more (Table 3-6) than that of Multimodal TOR warning, indicating that Multimodal TOR warning leads to better and faster response towards Steer Touch Time.

Table 3-5 Test of Fixed Effects for Steer Touch Time

Term	DF Num	DF Den	F-Value	P-Value
Gender	1.00	22.00	0.16	0.692
Warning Type	1.00	22.00	11.16	0.003
NDT type	3.00	66.00	4.06	0.010
Gender*Warning Type	1.00	22.00	0.84	0.370
Gender*NDT type	3.00	66.00	0.93	0.433
Warning Type*NDT type	3.00	66.00	1.08	0.365

Table 3-6 Conditional Means of Significant Factors for Steer Touch Time

Term	Fitted Mean	SE Mean	DF	T-Value	P-Value
Warning Type					
Auditory	2.76388	0.205531	30.4156	13.45	0.000
Multimodal	2.20454	0.205531	30.4156	10.73	0.000
NDT type					
Baseline	2.62257	0.224549	42.4210	11.68	0.000
Internet	2.77066	0.224549	42.4210	12.34	0.000
Math	2.10576	0.224549	42.4210	9.38	0.000
Video	2.43785	0.224549	42.4210	10.86	0.000

In addition to the Mixed-Effects Model, a Fisher LSD Pairwise Comparison was carried out for identifying significantly different pairs of NDT types. Table 3-7 conveys information about the difference of means of Steer Touch Time for each pair. As it can be observed that there were two significant pairs (highlighted in red in Table 3-7): Math-Internet and Math-Baseline. This result can also be confirmed from Figure 3-3.

Table 3-7 Fisher Individual Tests for Differences of Mean Steer Touch Time for NDT type

Difference of NDT type Levels	Difference of Means	SE of Difference	DF	Individual 95% CI	T-Value	P-Value
Internet - Baseline	0.148	0.201	66	(-0.254, 0.550)	0.74	0.464
Math - Baseline	-0.517	0.201	66	(-0.919, -0.115)	-2.57	0.012
Video - Baseline	-0.185	0.201	66	(-0.586, 0.217)	-0.92	0.362
Math - Internet	-0.665	0.201	66	(-1.067, -0.263)	-3.30	0.002
Video - Internet	-0.333	0.201	66	(-0.735, 0.069)	-1.65	0.103
Video - Math	0.332	0.201	66	(-0.070, 0.734)	1.65	0.104

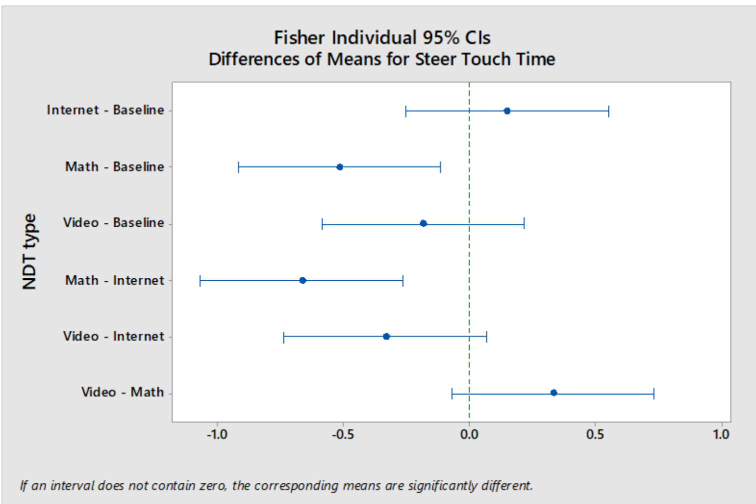

Figure 3-3 Differences of Means for Steer Touch Time

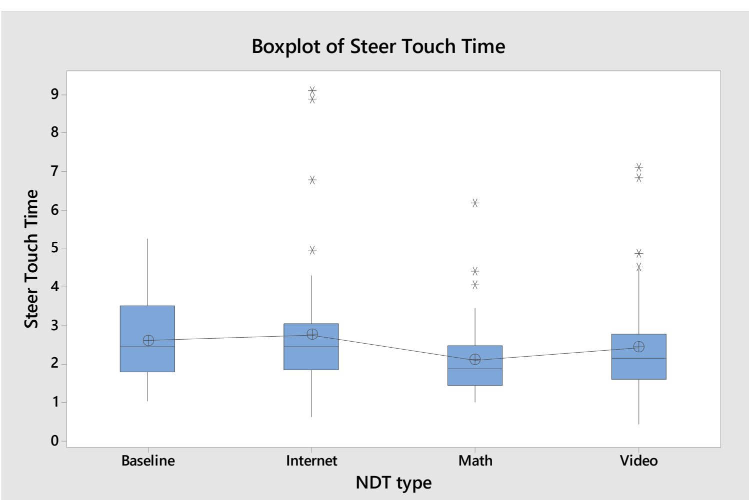

Figure 3-4 Boxplot comparing Steer Touch time for NDT type

Case-2: Mixed-Effects Model for Dependent Variables excluding Baseline

Table 3-8 gives information about the factors or independent variables for the mixed-effects models.

Table 3-8 Factor Information for Mixed Effects Model Excluding Baseline

Factor	Type	Levels	Values
Gender	Fixed	2	Female, Male
I.D.(Gender)	Random	24	F1(Female), F10(Female), F11(Female), F12(Female), F2(Female), F3(Female), F4(Female), F5(Female), F6(Female), F7(Female), F8(Female), F9(Female), M1(Male), M10(Male), M11(Male), M12(Male), M2(Male), M3(Male), M4(Male), M5(Male), M6(Male), M7(Male), M8(Male), M9(Male)
Warning Type	Fixed	2	Auditory, Multimodal
NDT type	Fixed	3	Internet, Math, Video
NDT duration(NDT type)	Fixed	6	10(Internet), 60(Internet), 10(Math), 60(Math), 10(Video), 60(Video)

Table 3-9 Test of Fixed Effects for Brake Time Excluding Baseline

Term	DF Num	DF Den	F-Value	P-Value
Gender	1.00	22.00	2.68	0.116
Warning Type	1.00	26.53	14.12	0.001
NDT type	2.00	68.45	5.28	0.007
Gender*Warning Type	1.00	26.53	1.74	0.198
Gender*NDT type	2.00	68.45	0.74	0.481
Warning Type*NDT type	2.00	26.53	1.77	0.189
NDT duration(NDT type)	3.00	71.19	0.24	0.871
Gender*Warning Type*NDT type	2.00	26.53	2.43	0.107
Gender*NDT duration(NDT type)	3.00	71.19	0.09	0.965
Warning Type*NDT duration(NDT type)	3.00	75.84	0.13	0.941
Gender*Warning Type*NDT duration(NDT type)	3.00	75.84	0.14	0.936

Table 3-10 Conditional Means for Significant Factors for Brake Time

Term	Fitted Mean	SE Mean	DF	T-Value	P-Value
Warning Type					
Auditory	2.69699	0.113797	28.425	23.70	0.000
Multimodal	2.39097	0.113797	28.425	21.01	0.000
NDT type					
Internet	2.75537	0.125280	40.520	21.99	0.000
Math	2.40139	0.125280	40.520	19.17	0.000
Video	2.47518	0.125280	40.520	19.76	0.000

Mixed-Effects Model for Brake Time under this category is shown above. Table 3-9 shows the tests of fixed effects. Only the Warning type and NDT type (both highlighted in red) impact the Brake Time significantly as their p-value is less than 0.05. Table 3-10 shows the conditional means for significant fixed factors. The mean Brake Time for Auditory TOR is greater than the mean Brake Time for Multimodal TOR, indicating that the latter is a significantly better TOR warning system than the former.

Moreover, for NDT type, the mean Brake Time for Surfing the Internet task is significantly higher than the other two non-driving tasks (Figure 3-6). This result is in-line with the research hypothesis that engagement in visual-manual tasks leads to longer reaction times in comparison to other non-driving tasks.

Fisher LSD Pairwise Comparison was also conducted to analyze NDT types for Brake Time. It was found that the mean Brake Time of Surfing the Internet task is significantly higher than the other two non-driving tasks. This result can be confirmed from Table 3-11 and Figure 3-5. And, as per Table 3-11 and Figure 3-5, the significant pairs (highlighted in red) obtained are Math-Internet and Video Internet.

Table 3-11 Fisher Tests for Differences of Mean Brake Time

Difference of NDT type Levels	Difference of Means	SE of Difference	DF	Individual 95% CI	T-Value	P-Value
Math - Internet	-0.354	0.115	68.4462	(-0.583, -0.125)	-3.08	0.003
Video - Internet	-0.280	0.115	68.4462	(-0.510, -0.051)	-2.44	0.017
Video - Math	0.074	0.115	68.4462	(-0.156, 0.303)	0.64	0.523

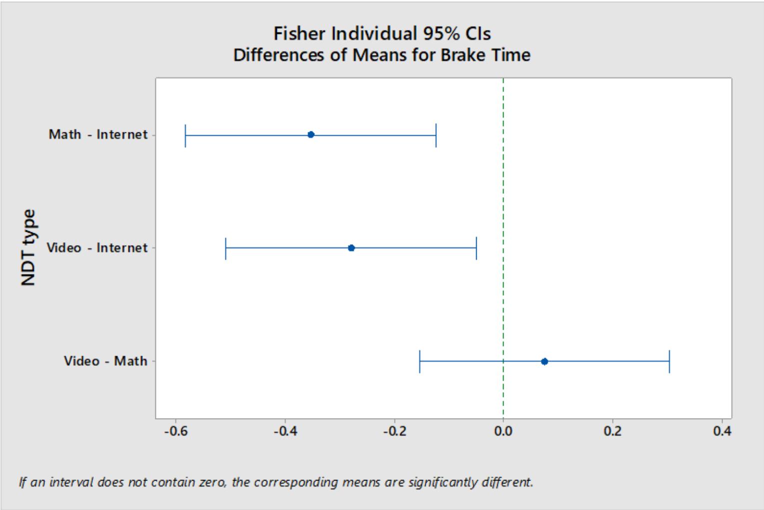

Figure 3-5 Differences of Means for Brake Time for NDT type

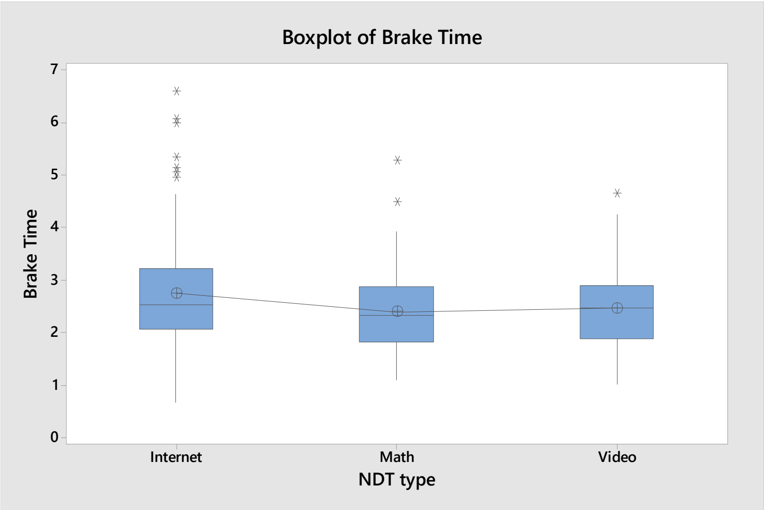

Figure 3-6 Boxplot comparing Brake Time of NDT type

Mixed-Effects Model for Steer Touch Time is shown as under. The significant factors of the analysis were found to be – Warning type and NDT type which are highlighted in red color in Table 3-12.

Table 3-12 Tests of Fixed Effects for Steer Touch Time

Term	DF Num	DF Den	F-Value	P-Value
Gender	1.00	22.00	0.41	0.530
Warning Type	1.00	22.00	6.26	0.020
NDT type	2.00	110.00	6.63	0.002
Gender*Warning Type	1.00	22.00	0.90	0.353
Gender*NDT type	2.00	110.00	0.13	0.881
Warning Type*NDT type	2.00	110.00	1.01	0.369
NDT duration(NDT type)	3.00	110.00	0.12	0.948
Gender*NDT duration(NDT type)	3.00	110.00	1.66	0.179
Warning Type*NDT duration(NDT type)	3.00	110.00	0.90	0.441
Gender*Warning Type*NDT duration(NDT type)	3.00	110.00	1.08	0.360

Table 3-13 Conditional Means of Significant Fixed Factors for Steer Touch Time

Term	Fitted Mean	SE Mean	DF	T-Value	P-Value
Warning Type					
Auditory	2.68750	0.244094	30.5107	11.01	0.000
Multimodal	2.18744	0.244094	30.5107	8.96	0.000
NDT type					
Internet	2.77066	0.246401	32.6365	11.24	0.000
Math	2.10598	0.246401	32.6365	8.55	0.000
Video	2.43577	0.246401	32.6365	9.89	0.000

Table 3-14 Fisher Individual Tests for Differences of Means for Steer Touch Time

Difference of NDT type Levels	Difference of Means	SE of Difference	DF	Individual 95% CI	T-Value	P-Value
Math - Internet	-0.665	0.183	110.000	(-1.027, -0.303)	-3.64	0.000
Video - Internet	-0.335	0.183	110.000	(-0.697, 0.027)	-1.83	0.069
Video - Math	0.330	0.183	110.000	(-0.032, 0.692)	1.81	0.074

Fisher LSD Pairwise Comparison was conducted for factor NDT type for response variable Steer Touch Time. It can be noted from the output of Table 3-13, Table 3-14 and Figure 3-8 that for Surfing the Internet task, the mean Steer Touch Time was higher in comparison to Watching a Video task (p-value>0.05) and was significantly higher in comparison to Oral Math Question task (p-value<0.05). While the differences between mean steer touch time for Oral Math Question task and Watching a Video task were not significant as their p-value was more than 0.05.

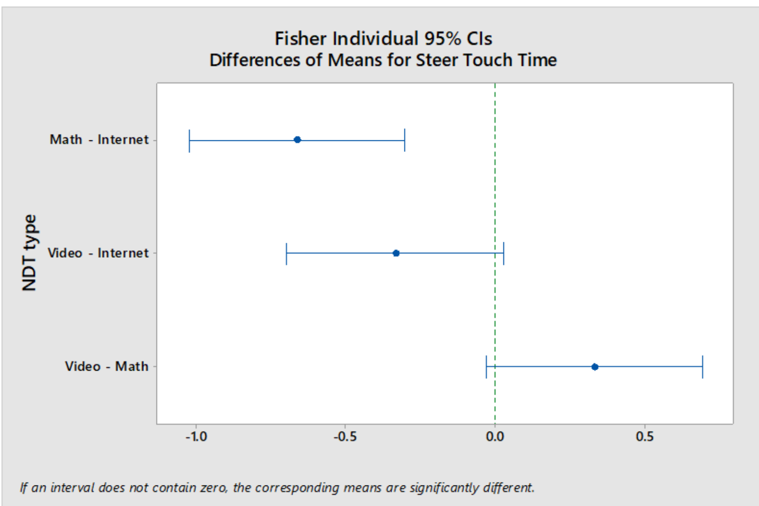

Figure 3-7 Differences of Means for Steer Touch Time for NDT type

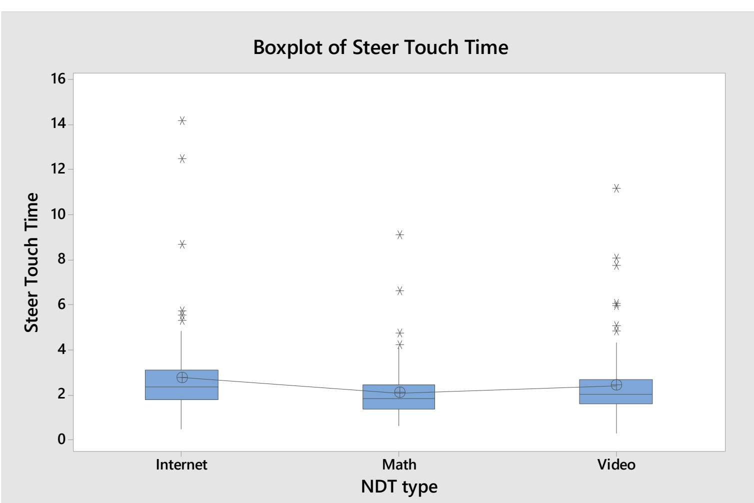

Figure 3-8 Boxplot comparing Steer Touch Time for NDT type

Subjective Ratings

Participants were also given a Post-Drive Questionnaire in which they were asked to score each TOR warning type on four grounds – Comfortability, Effectiveness, Expressiveness, and Perceptibility. In the graph below, the scores of each participant can be seen for each TOR warning type.

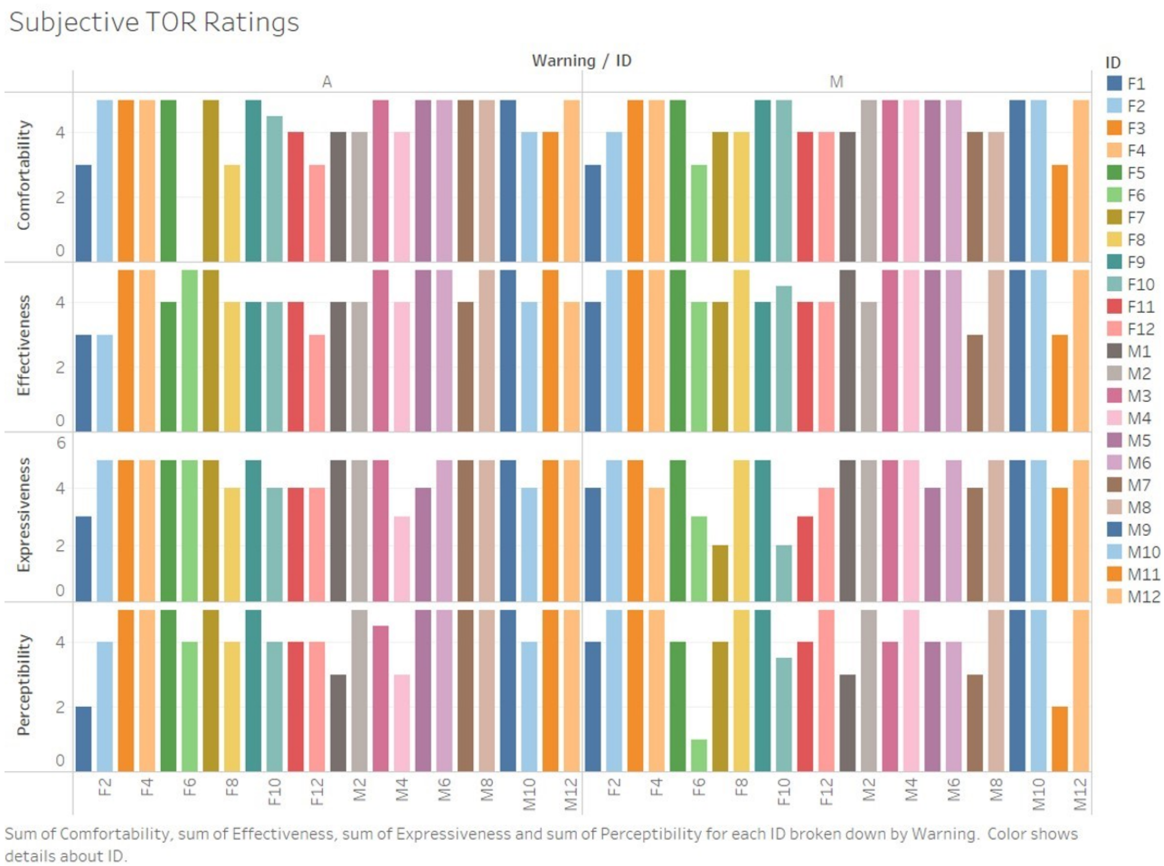

Figure 3-9 Bar Charts depicting scores of each participant for each TOR type. X-axis includes I.D., TOR warning type (A-Auditory, M-Multimodal). Y-axis consists of the scores on a scale of 5 for 4 parameters

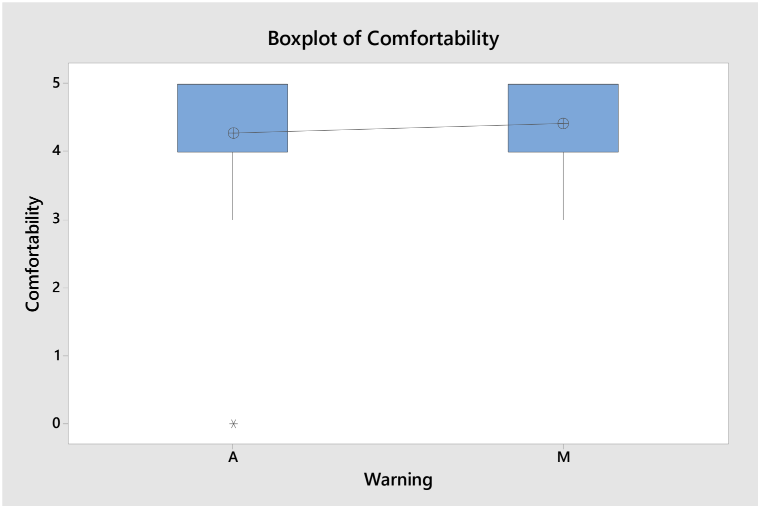

Figure 3-10 Boxplot comparing TORs based on Comfortability

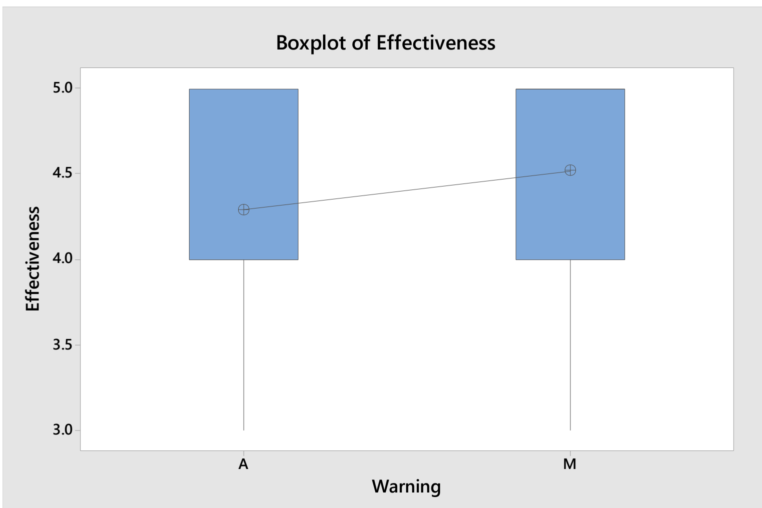

Figure 3-11 Boxplot comparing TORs based on Effectiveness

A two-sample t-test was conducted for each parameter for the comparison of subjective ratings of Auditory TOR and Multimodal TOR. It was found that for Comfortability (Figure 3-10), Multimodal TOR had a slightly better mean score (4.42) than Auditory TOR (4.27). However, the p-value = 0.601, made the result not significant. For Effectiveness scores (Figure 3-11), again Multimodal TOR faired with a mean score of 4.52 against Auditory TOR, which had a score of 4.29. But, the p-value was 0.243, which made the result not significant.

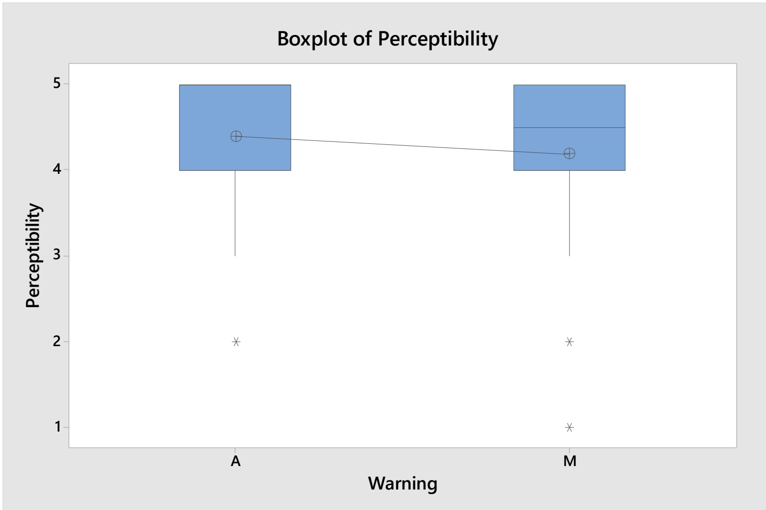

Figure 3-12 Boxplot comparing TORs based on Perceptibility

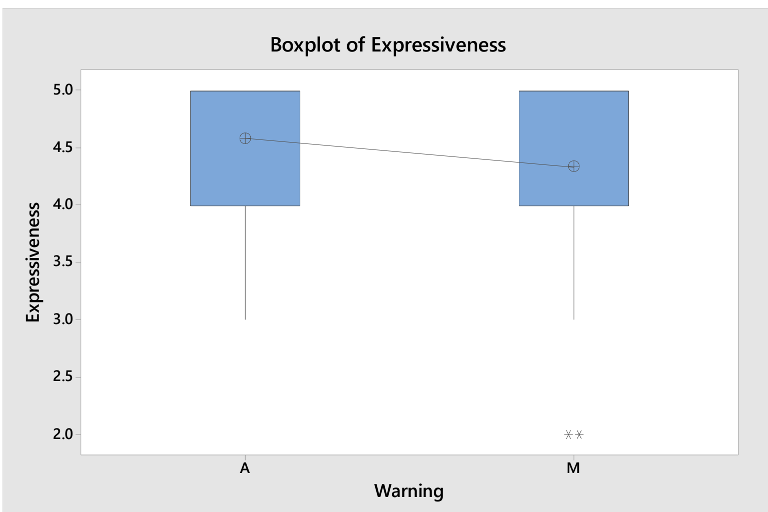

Figure 3-13 Boxplot comparing TORs based on Expressiveness

For the Perceptibility (Figure 3-12), Auditory TOR (mean score 4.40) was rated better than Multimodal TOR (mean score 4.19). Although, the result is not significant because of the p-value, which was 0.454 (>0.05). For the Expressiveness (Figure 3-13), the result was the same. Auditory TOR was rated more with a mean score of 4.58 in comparison to Multimodal TOR, which had a mean score of 4.33. P-value was 0.299 (>0.05) making the result not significant.

In addition to the Post-Drive Questionnaire, the participants were also given the NASA-TLX document, which had to be filled by them after the end of both drives (Baseline Drive and NDT Drive) to assess his/her workload during the drives. The below graph shows the scores for each type of workload demand for each drive.

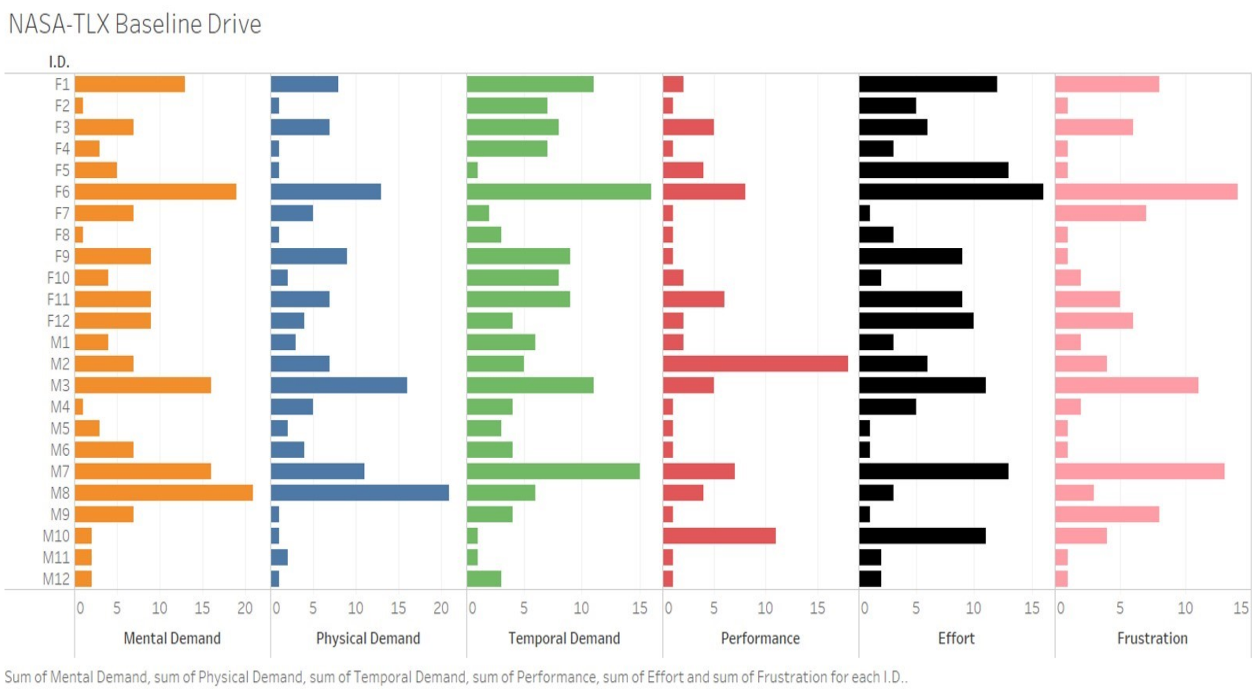

Figure 3-14 NASA-TLX scores for Baseline Drive

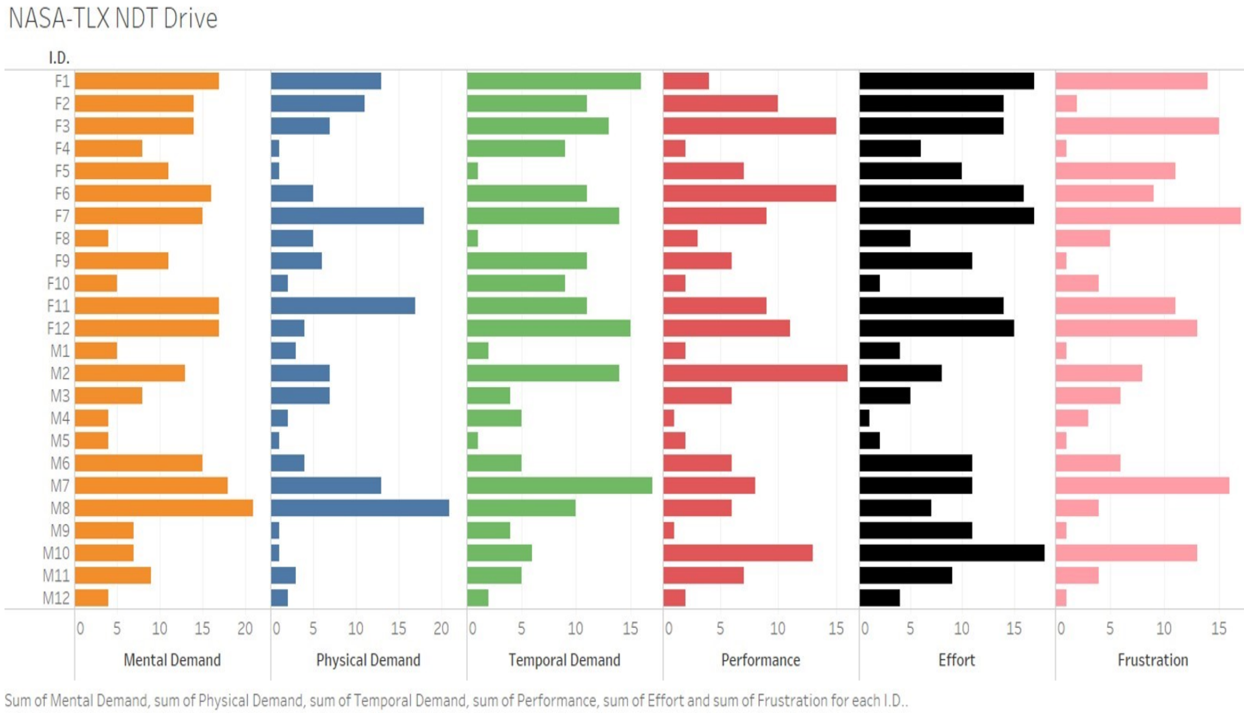

Figure 3-15 NASA-TLX scores for NDT Drive

A two-sample t-test was conducted to compare the scores for each demand type of the NASA-TLX document for both the drives (Baseline Drive and NDT Drive).

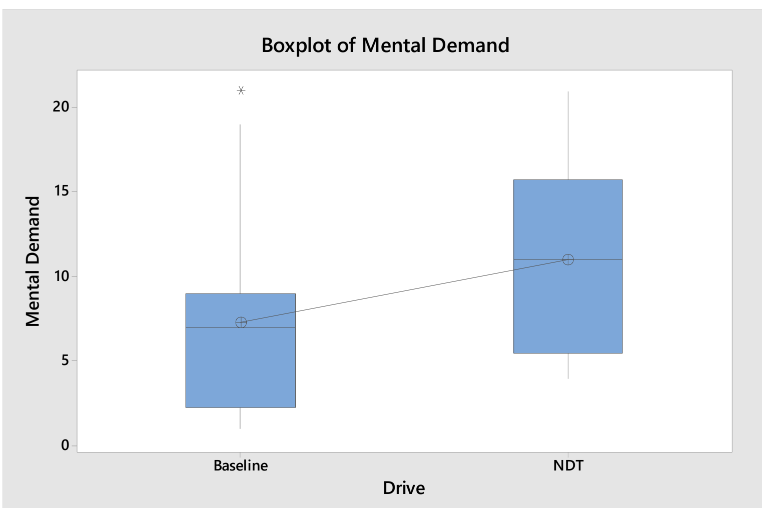

Figure 3-16 Boxplot for comparing Mental Demand of both Drives

For Mental demand (Figure 3-16), the expectation was that the scores will be higher for NDT drive than Baseline drive because, in NDT drive, the participant was heavily engaged in non-driving tasks. From the two-sample t-test, it can be observed that the mean value of mental demand in NDT drive (11) was significantly (p-value = 0.027) more than that of the Baseline drive (7.29).

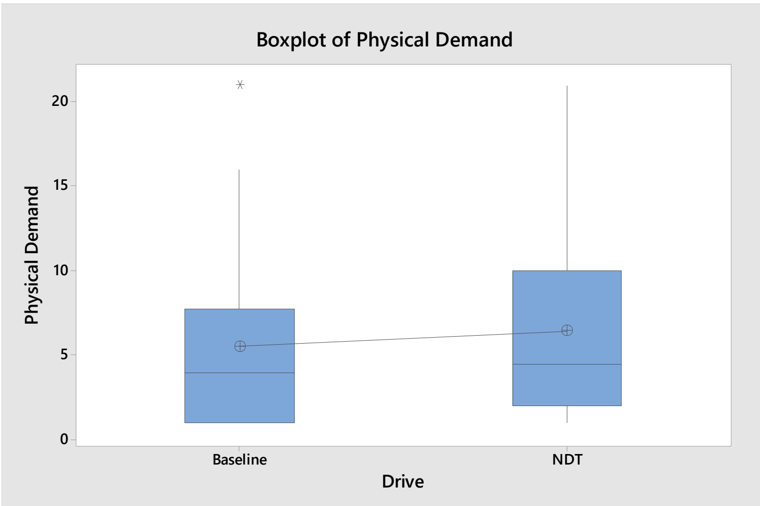

Figure 3-17 Boxplot for comparing Physical Demand of both Drives

For Physical demand (Figure 3-17), the expectation of scores was similar to the scores of Mental demand. From the two-sample t-test, it can be observed that the mean score of NDT drive (6.46) was more than that of Baseline drive (5.54), although, the difference was not significant (p-value = 0.576).

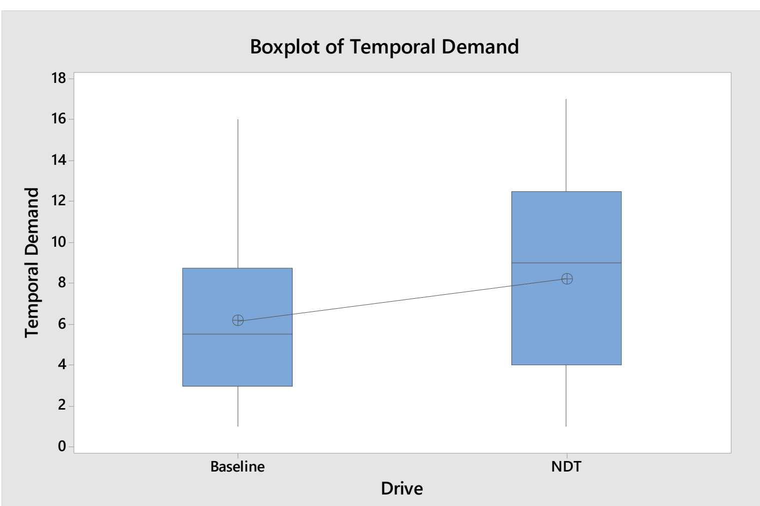

Figure 3-18 Boxplot for comparing Temporal Demand of both Drives

For Temporal demand (Figure 3-18), the expectation of the scores was similar as well. In the two-sample t-test, that was conducted for comparison, it was found that the mean score of NDT drive (8.21) was more than that of Baseline drive (6.17). However, the difference was not significant because of p-value = 0.138.

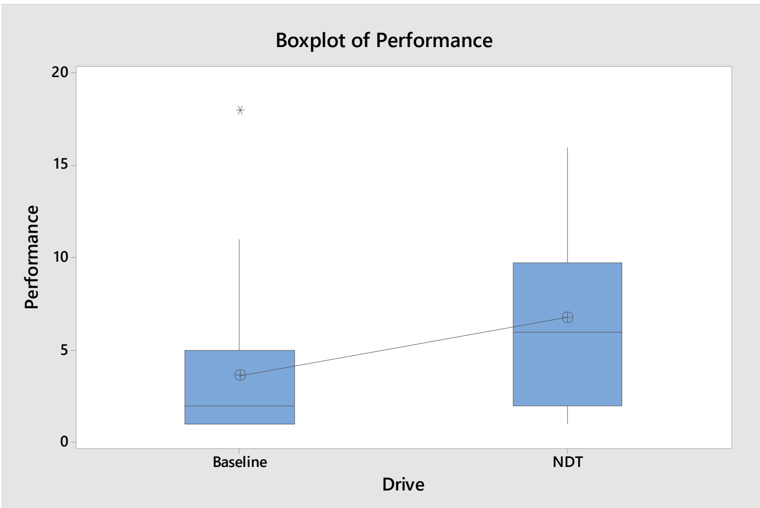

Figure 3-19 Boxplot for comparing Performance of both Drives

Now, for Performance (Figure 3-19), a low score indicates perfect performance in a task while a higher score was inclined more towards failure in performance for a particular task. The expectation was that the performance score will be less for Baseline drive in comparison to NDT drive because, in the former one, the participant was not engaged in other non-driving tasks. Hence, he/she was expected to perform better comparatively and take control of the car in a smooth, effective and efficient manner for the Baseline Drive. From the two-sample t-test, it can be seen that the mean performance score was significantly (p-value = 0.016) less for Baseline drive (3.63) in comparison to NDT drive (6.79).

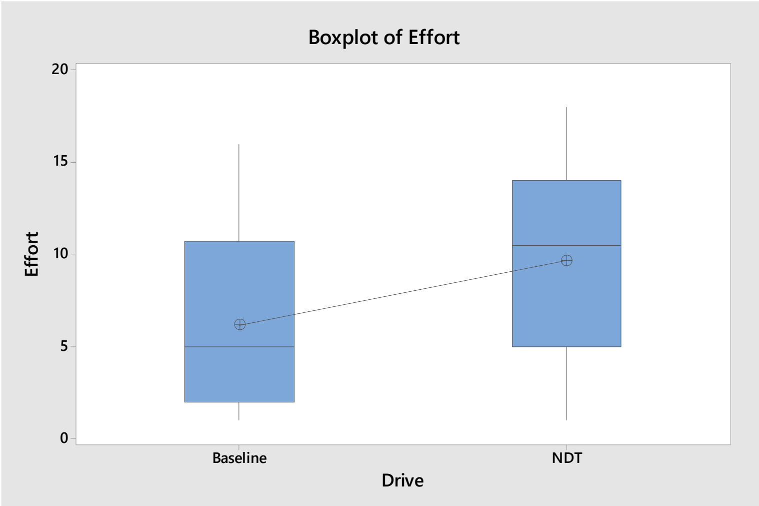

Figure 3-20 Boxplot for comparing Effort in both Drives

Similarly, for Effort (Figure 3-20), it was expected that for Baseline drive, the participant will require less effort in comparison to NDT drive. A two-sample t-test was conducted and it was found that the former Drive had effort scores towards the low side with the mean value of 6.17 while the latter Drive had a mean effort score of 9.67. This difference was significant because the p-value was 0.019 (<0.05).

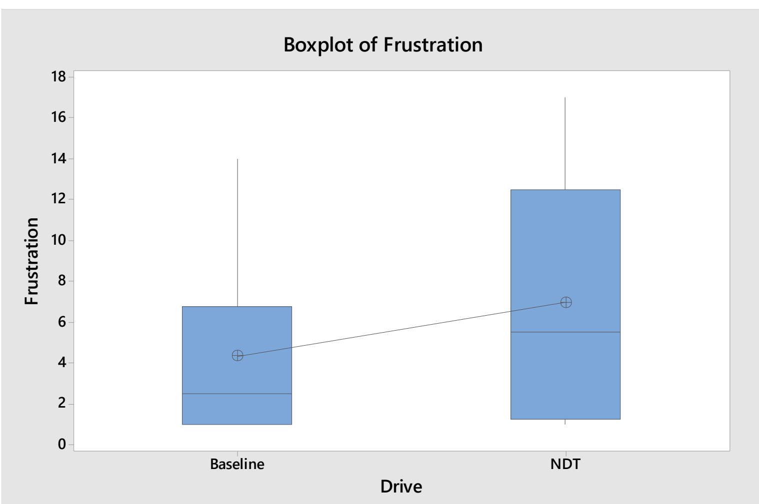

Figure 3-21 Boxplot for comparing Frustration in both Drives

For Frustration (Figure 3-21), it was expected that a participant will be frustrated more in NDT drive in comparison to Baseline drive because, in the former drive, he had to take over 12 times while engaged in non-driving tasks which may induce stress and frustration inside the participant. While in Baseline drive, he had to take over two times only and was also not engaged in any non-driving tasks. A two-sample t-test was conducted for comparison and it was found that the mean value of frustration was more for NDT drive (6.96) than the Baseline drive (4.33). However, this difference was not significant as the p-value was 0.066.

Chapter 4 Conclusion and Future Work

The research study was designed to address three research questions. The first research question was about whether Multimodal TOR warnings (consisting of a semantic audio file with simple sentences along with the visual icon and tactical) can lead to better drivers' responses to TOR than Auditory TOR warnings (consisting of semantic audio with simple sentences). This question corresponded to the need of studying the effect of warning type on drivers' reactions towards takeover requests during conditional automated driving. From the results of Mixed-Effects Model for Brake Time and Steer Touch Time, it was statistically evident that Multimodal TOR warning was significantly better than Auditory TOR warning because the mean Brake Time value and the mean Steer Touch Time value for Multimodal TOR warning were significantly less in comparison to that of Auditory TOR warning. In addition to the objective drivers' measures, subjective ratings of Comfortability and Effectiveness during the takeover process for a Multimodal TOR warning type were also significantly better than Auditory TOR warning type, indicating that the participants felt comfortable and were able to respond effectively and quickly towards Multimodal TOR warning in comparison to Auditory TOR warning.

The second research question was about whether the types of non-driving tasks will have different cognitive loads on the drivers and in turn, will impact drivers' re-engagement in the driving task. It was evident from the Mixed-Effects Model and Fisher LSD Pairwise Comparison of NDT type for Brake time and Steer Touch Time that the mean values of these responses are different for each NDT type, leading to different cognitive engagement of drivers in different non-driving tasks. Also, it was observed that visual-manual tasks (surfing the internet on phone) lead to the poor performance of drivers in terms of reaction time and response towards the takeover request. The Brake Time and Steer Touch Time for visual-manual tasks were significantly longer in comparison to the other two non-driving tasks (Watching a Video on the in-vehicle infotainment screen and Oral Math Questions) for Mixed-Effects Model Case-2.

Moving onto the third research question which stated that the longer duration of engagement in a non-driving task will lead to longer reaction times and worse driving performance. From the Mixed-Effects Model, it can be seen that non-driving task duration did not show significant effects on all the dependent variables, indicating that future research should be done while deciding the levels of NDT duration. In this study, the levels of NDT duration were 10 seconds and 60 seconds. It may be the reason that the differences between the 10 seconds and 60 seconds were not large enough. Also, no significant gender effects on Brake Time and Steer Touch Time responses were observed during this study.

However, since it was a simulator-based study, which means that there were some limitations associated with it. First, being a simulator-based study implied that the results were obtained in a non-naturalistic setting. Moreover, there were limited physical, perceptual, and behavioral fidelity which affected participants' opinions. Plus, for the Baseline NDT type, the cognitive state of the participants could not be controlled during the data collection.

Future work can be done to validate the findings from this study in a real-world setting, as it is expected that the quantitative differences observed in this simulator-based study will differ from the real-world setting driving situations. From the design of the TOR warning perspective, ambient lights in the form of LEDs can be accommodated on the instrument panel for the Multimodal TOR as it is expected that ambient lights will act as a better visual stimulus for people as opposed to a small icon in the instrument cluster. Moreover, another research can be about the study of varying output format (e.g., voice decibel levels) of the auditory warning and vibration frequency of the vibrotactile seat, depending on the severity of the accident if the driver fails to comprehend the takeover request warning.

Appendices

The supporting documents of the research study are as under:

Appendix 1: Pre-Drive Questionnaire

1. Your Name________________________________
2. Your Contact (phone and email)

   ____

3. What is your Age? _______ years
4. What is your Gender? **(circle one)**
   - Male
   - Female
   - Other
5. What is your highest level of education? **(either completed or ongoing)**
   - High School
   - Some College Education
   - Bachelor's Degree
   - Master's Degree or above
6. Since how long do you own a driving license? **(circle one)**
   - Within 1 year
   - Between 1 year and 4 years
   - Between 4 years and 8 years
   - More than 8 years
7. How often do you commute? **(circle one)**
   - Daily

- 3-4 times a week
- Once or twice in a week
- Other (please specify) ____

8. How much is your commute in Mileages frequently? **(circle one)**
    - Less than 10 miles
    - Between 10 and 20 miles
    - Between 20 and 40 miles
    - More than 40 miles
9. What type of driver-assist technologies does your car have or you have used while driving? **(circle all that apply)**
    - **Forward crash warning:** Forward collision warning alerts you of an impending collision with a slower-moving or stationary car in front of you. Unlike Automatic Emergency Braking, it will not slow or stop your vehicle for you.
    - **Adaptive cruise control:** Will maintain a set speed when there are no vehicles immediately in front of you in a lane and can adaptively increase or decrease your car's speed as needed to maintain a set separation distance when a vehicle is immediately in front of you. Some versions can completely stop your car in traffic jams, and some can automatically accelerate again after the vehicle has come to a complete stop.
    - **Lane-keeping assists:** Lane Keeping Assist may gently steer you back into your lane if you begin to drift out of it.
    - **Lane Departure Warning:** Lane departure warning systems alert you if you're drifting out of your lane using visual, vibration or sound warnings.

- **Blind Spot Monitor:** These monitors, often an icon in the side or rear-view mirror, warn you of cars driving in your blind spots. They may provide an additional warning, such as blinking icons or an audible or haptic warning if you use your turn signal when a car is in the lane.
- **Adaptive Light Control:** Adaptive headlights are an active safety feature designed to make driving at night or in low-light conditions safer by increasing visibility around curves and over hills. When driving around a bend in the road, standard headlights continue to shine straight ahead, illuminating the side of the road and leaving the road ahead of you in the dark. Adaptive headlights, on the other hand, turn their beams according to your steering input so that the vehicle's actual path is lit up.
- **Automatic (Assisted) Braking:** This feature applies the brakes – either gradually to maintain a safe following distance or even to a complete stop – to help prevent or reduce the severity of a crash into the vehicle ahead.
- **GPS Navigation:** A GPS navigation system is a GPS receiver and audio/video (AV) components designed for a specific purpose such as a car-based or hand-held device or a smartphone app. The global positioning system (GPS) is a 24-satellite navigation system that uses multiple satellite signals to find a receiver's position on earth.
- **Tire Pressure Monitoring:** The purpose of the tire pressure monitoring system (TPMS) in your vehicle is to warn you that at least one or more tires are significantly under-inflated, possibly creating unsafe driving conditions. The TPMS low tire pressure indicator is a yellow symbol that illuminates on the

dashboard instrument panel in the shape of a tire cross-section (that resembles a horseshoe) with an exclamation point.

10. Have you ever received a speeding ticket?
    - Yes
    - No
11. Have you ever been distracted while driving (talking to passengers, use of phone, eating, etc.)?
    - Yes
    - No

If you marked Yes, then what type of distraction have you experienced on a daily basis: **(circle all that apply)**

- Talking on Phone
- Texting or Web Searching on Phone
- Day Dreaming
- Talking with the passengers
- Other (please specify) ________________________________

12. Have you ever tried to change lanes without first checking your rear-view mirror and side mirrors?
    - Yes
    - No

If you marked Yes, then how many times you did that for the past month? **(circle one)**

- Between 1 to 5 times
- Between 5 to 10 times
- More than 10 times

13. Have you ever get honked at by the car behind when you are changing the lane?
    - Yes
    - No

If you said yes, then how many times you did that for the past month? **(circle one)**

- Between 1 to 5 times
- Between 5 to 10 times
- More than 10 times

14. Do you ever forget to check your mirror or surrounding traffic before pulling out, making a turn, etc.?

- Yes
- No

If yes, then how many times you did for the past month? **(circle one)**

- Between 1 to 5 times
- Between 5 to 10 times
- More than 10 times

15. Have you ever attempted to pass a vehicle that you hadn't noticed was signaling its intention to turn left?

- Yes
- No

If yes, then how many times you did for the past month? **(circle one)**

- Between 1 to 5 times
- Between 5 to 10 times
- More than 10 times

16. Please rate yourself in terms of being a safe driver **(on a scale of 5, with 5 being the SAFEST driver)**

0 1 2 3 4 5

17. Please rate yourself in terms of being an aggressive driver **(on a scale of 5, with 5 being the MOST AGGRESSIVE driver)**

0 1 2 3 4 5

18. How much confident you are towards your driving skills? **(on a scale of 5, with 5 being the MOST CONFIDENT driver)**

0 1 2 3 4 5

19. How much you trust automated driving technologies that are safer than yourself? **(on a scale of 5, with 5 being the most trustable of the automated driving technologies)**

0 1 2 3 4 5

Appendix 2: NASA-TLX Form

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

Name: ______________________ Task: _______________________ Date: _____________

Mental Demand: How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc)? Was the mission easy or demanding, simple or complex, exacting or forgiving?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

Physical Demand: How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the mission easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

Temporal Demand: How much time pressure did you feel due to the rate or pace at which the mission occurred? Was the pace slow and leisurely or rapid and frantic?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

Performance: How successful do you think you were in accomplishing the goals of the mission? How satisfied were you with your performance in accomplishing these goals?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

Effort: How hard did you have to work (mentally and physically) to accomplish your level of performance?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

Frustration: How discouraged, stressed, irritated, and annoyed versus gratified, relaxed, content, and complacent did you feel during your mission?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

Appendix 3: Post Drive Questionnaire

1. Your Name: ____________________________

2. How much comfortable was it to take-over for (on a scale of 5, with **5 being Easiest** and **0 being Most difficult**) *NOTE: TOR means: Take Over Request*

    - Multimodal TOR?

0 1 2 3 4 5

    - Auditory TOR?

0 1 2 3 4 5

3. Please rate the overall effectiveness of **Multimodal Take Over Request** on a scale of 5, **with 5 being the BEST.**

0 1 2 3 4 5

4. Please rate the overall effectiveness of **Auditory Take Over Request** on a scale of 5, **with 5 being the BEST.**

0 1 2 3 4 5

5. Please rate the perceptibility of **Multimodal Take Over Request** on a scale of 5, **with 5 being the Easy to perceive.**

0 1 2 3 4 5

6. Please rate the perceptibility of **Auditory Take Over Request** on a scale of 5, **with 5 being the Easy to perceive.**

0 1 2 3 4 5

7. Please rate the legibility of icon and text on the Instrument Cluster during **Multimodal Take Over Request** on a scale of 5, **with 5 being Most legible.**

0 1 2 3 4 5

8. Please rate the conveying of information (expressiveness) of **Multimodal Take Over Request** on a scale of 5, **with 5 being the Easy to understand the conveyed information.**

0 1 2 3 4 5

9. Please rate the conveying of information (expressiveness) of **Auditory Take Over Request** on a scale of 5, **with 5 being the Easy to understand the conveyed information.**

0 1 2 3 4 5

10. Did you recognize the visual icon of the Multimodal Take Over Request? **(VISIBILITY)**

    - Yes, for all Non-driving task
    - No, for all Non-driving task

- Yes, for some (Mention the ones for which you recognized the Visual Icon)

  ____

  ____

11. Under the **Auditory TOR** condition, were you given enough reaction time when you were asked to take over the control of the car, while you were **Watching a Video**?
    - Yes
    - No

If you marked No, then according to you, how much time in total should have been given? (in the study, you were given 7 seconds) _____ Seconds

12. Under the **Auditory TOR** condition, were you given enough reaction time when you were asked to take over the control of the car, while you were **Mental Math Calculation Questions**?
    - Yes
    - No

If you marked No, then according to you, how much time in total should have been given? (in the study, you were given 7 seconds) _____ Seconds

13. Under the **Auditory TOR** condition, were you given enough reaction time when you were asked to take over the control of the car, while you were **Surfing the Internet**?
    - Yes
    - No

If you marked No, then according to you, how much time in total should have been given? (in the study, you were given 7 seconds) _____ Seconds

14. Under the **Multimodal TOR** condition, were you given enough reaction time when you were asked to take over the control of the car, while you were **Watching a Video**?
    - Yes
    - No

If you marked No, then according to you, how much time in total should have been given? (in the study, you were given 7 seconds) _____ Seconds

15. Under the **Multimodal TOR** condition, were you given enough reaction time when you were asked to take over the control of the car, while you were **Mental Math Calculation Questions**?
    - Yes
    - No

If you marked No, then according to you, how much time in total should have been given? (in the study, you were given 7 seconds) _____ Seconds

16. Under the **Multimodal TOR** condition, were you given enough reaction time when you were asked to take over the control of the car, while you were **Surfing the Internet**?
    - Yes
    - No

If you marked No, then according to you, how much time in total should have been given? (in the study, you were given 7 seconds) _____ Seconds

17. Did you feel panicked upon receiving Take Over Request?
    - Yes, for both TOR type
    - No, for both TOR type
    - Yes, for only one TOR type (mention that TOR type)

      ____

      ____

18. Do you feel that you were fully engaged in the Non-driving tasks during the time of Take Over Request?
    - Yes
    - No

19. Please rate yourself in terms of being a safe driver **(on a scale of 5, with 5 being the SAFEST driver)**

0 1 2 3 4 5

20. Please rate yourself in terms of being an aggressive driver **(on a scale of 5, with 5 being the MOST AGGRESSIVE driver)**

0 1 2 3 4 5

21. How much confident you are towards your driving skills? **(on a scale of 5, with 5 being the MOST CONFIDENT driver)**

0 1 2 3 4 5

22. How much you trust automated driving technologies that are safer than yourself? **(on a scale of 5, with 5 being the most trustable of the automated driving technologies)**

0 1 2 3 4 5

23. What was the most challenging thing during the Take Over Request?

____

24. What improvements will you suggest for the Take Over warning system?

____

Appendix 4: Normality Test for Brake Time

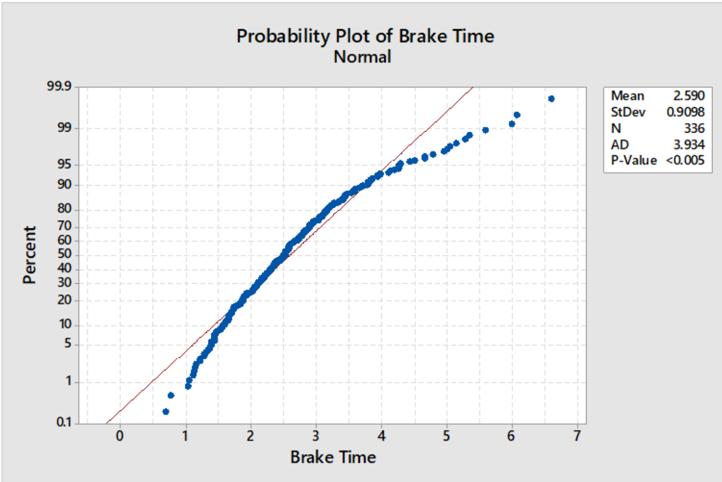

Figure A4-1 Normality test for Brake Time

Appendix 5: Normality Test for Steer Touch Time

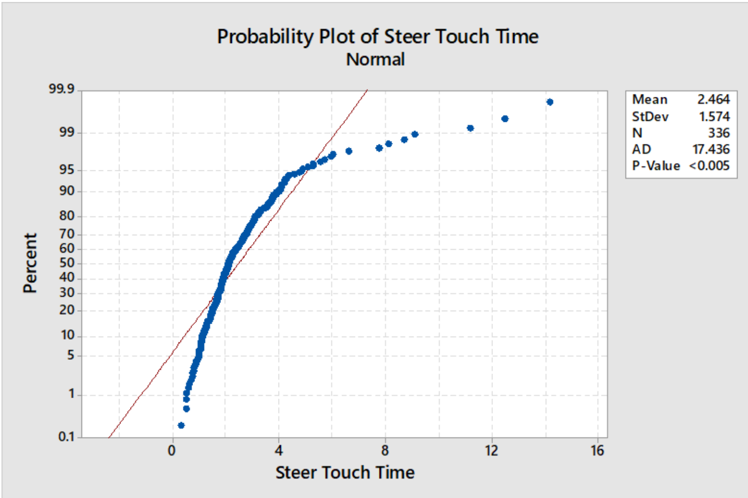

Figure A5-2 Normality test for Steer Touch Time

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