Should I give or should I take? Choice issues in automated vehicle control

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Abstract

The advent of automation and communication in vehicles have provided new opportunities to mitigate traffic, increase productivity, and reduce emission. Despite these advantages, connected and autonomous vehicles (CAVs) face deployment and adoption challenges arising from human drivers lack of acceptance and willingness to give control to CAVs. Another roadblock in success of CAVs is drivers' situational awareness and mental workload in safely taking control back from CAVs when required. To gain further insights into behavioral responses of drivers to automation, in this study a stated preference laboratory experiment is designed employing Virtual Reality Immersive Environment (VIRE) driving simulator. Two sets of experiments are conducted: 1) give-away experiments, where participants have full control of the vehicle with an option of giving control to CAV en-route as desired, 2) take-away experiments, where participants are driven by CAV and have to take control back from CAV due to sensor failure. Different traffic, weather and lighting (day, night) conditions are tested. The option to multi-task is available when the participant is being driven by CAV. The aim is to investigate under what conditions drivers are more willing to give control to the automated vehicle and have higher situational awareness to safely take back control from automated vehicles. The NASA-Task Load Index and Detection Response Task Index are used to evaluate participants mental workload. The results obtained show that weather condition and congestion level play a significant role in drivers' willingness to give control to CAV. The results also show that multi-tasking and congestion have the most impact on drivers' situational awareness and mental workload in taking back control safely from CAV.

Keywords: virtual immersive reality environment, laboratory experiments, human machine interaction, connected and autonomous vehicles, mental workload, situational awareness

1. Introduction

In recent years in order to make vehicles safer, reduce human drivers' error, reduce congestion, and reduce GHG emissions, attention has been given to intelligent vehicles that support or overtake driving tasks. Self-driven connected and autonomous vehicles (CAVs) are the disruptive technological innovation that are expected to transform urban traffic, mobility patterns, land use, and economy. It is no longer a question of if CAV technology will be adopted, but when, in what form, at what rate, and through what kind of evolutionary path? Technologies like Tesla's Autopilot are already in the market, and it is expected that by 2045 as much as 45% of the fleet could be CAV-based (Kuhr et al.,

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2017). The current level of automation is at level 3 where, although steering and accelerating can be performed by the vehicle, the human is still in the loop and has to take control back when necessary or can decide not to give control at all. Therefore, it will be long before 100% level 5 CAVs be on the road. An important factor that has a major effect on the effectiveness of CAVs is drivers' willingness to give control to the system or take it back safely when required. The associated challenge with taking control back safely is driver's mental workload and situational awareness in the operational safety of automated driving. In the case of automation, drivers become passive observers as opposed to information processors resulting in a decrease of drivers' situational awareness and an increase in accident rate (Hirose et al., 2015). In recent years there have been accidents involving CAV where drivers failed to take back control safely from the CAV when there was malfunction in CAV system.

Online stated preference surveys (SP) have been widely used in the recent years to explore the factors influencing travelers' acceptance of automated vehicles (Becker & Axhausen, 2017). However, online based SP surveys lack realism, especially when it comes to new and upcoming technologies. Driving simulators and field experiments have also been used to investigate situational awareness and mental workload of drivers when it comes to safely operating automated vehicles (Stapel et al., 2017). However, they also have their own limitations e.g. lack of interaction with environment and controlled environments. Moreover, field studies face the problem of replicability. As a result, virtual reality-based SP surveys have been gaining interest among researchers to study behavioural responses to CAVs, since it allows users to form a visual image of the innovative alternative as opposed to just purely mental image (Djavadian et al., 2019). To gain further insights into behavioral responses of drivers to automation, in this study a stated preference laboratory experiment is designed employing Virtual Reality Immersive Environment (VIRE) driving simulator (Farooq et al., 2018). The aim is to answer following research questions:

1. Under what conditions drivers are more willing to give control to CAV en-route?
2. Under what conditions drivers have higher situational awareness and ability to safely take back control from CAV?

The remainder of this paper is organized as follows. In the background section, an overview of existing literature on drivers' adaptation to CAVs is presented. The methodology section presents the design of our SP experiments employing VIRE driving simulator. Then, results and analysis are presented, followed by a summary and future work directions.

2. Background

Connected and autonomous vehicles have proven in simulation settings that they have the potential of reducing negative impacts of transportation (congestion, emission, accidents). In their recent study, Farooq & Djavadian (2019) developed a dynamic distributed traffic management system using network of intelligent intersections and CAVs that has the potential of reducing travel time by 40 % while increasing network throughput and reducing green house gas emission. However, as shown by Alfaseeh et al. (2019) the efficiency of such a system depends on the market penetration rate of CAVs, which is directly related to willingness of drivers to adapt to CAVs and give them control either partially or fully. Therefore, it is necessary to find insight into the adaptation of drivers to CAVs. Online and paper-based SP surveys have been deployed in the majority of experiments to test the factors affecting travelers' acceptance of CAVs. Becker & Axhausen (2017) provide detailed review of recent studies who have used SP.

Djavadian et al. (2019) recently investigated willingness of drivers choosing CAV over human driven vehicles (HDV) while going from their origin to their destination. In their study, participants were able to experience being driven by CAV and driving themselves, choosing the one that they preferred the most. The focus of the study conducted by Djavadian et al. (2019) was on Level 5 automated vehicles, but as discussed earlier it will be long before we can expect 100% Level 5 vehicles on the road. As such, it is important to look into under what conditions drivers are willing to give control to vehicles, in the presence of partially automated vehicles.

Aside from drivers' willingness to adapt to CAVs and give them control, another major factor affecting the success of CAVs is the drivers' ability to operate the intelligent vehicles and be able to take back control safely when necessary. This is of particular interest to automobile manufacturers in order to provide clear and on-time instructions to drivers when it is necessary for them to take back control from the vehicle.

Many studies have investigated driver attentiveness and workload in the context of the transition from automated driving to manual. Stapel et al. (2019) evaluated workload using both automation-inexperienced and automation-experienced participants driving in a in a Tesla Model S on public highways in various traffic complexities. In the experiments, when using automation, automation-experienced drivers perceived a lower workload, while automation-inexperienced drivers perceived their workload to be similar to manual driving. It was found that drivers under-estimate the actual task load of attentive monitoring due to the detection-response task indicated an increase in cognitive load with automation.

Hirose et al. (2015) investigated the driving characteristics of low-alert drivers after a change from automated driving to manual driving. The participant is driven by an AV at high speed along a highway and the driving mode changes from automated to manual, after which the participant must react to a vehicle turning in front of them. A significant difference was observed in both reaction time and brake pedal operation when the driver is in a low-alert state relative to a normal-alert state, resulting in unsuccessful collision avoidance in some instances and giving credence to the need for a prior and explicit warning of transition of control.

Merat et al. (2014) designed a driving simulator to investigate drivers' ability to resume manual control of an AV. The two situations considered were a transition of control at a regular, system-based interval and a transition of control based on the length of time drivers were looking away from the road. Driver attentiveness was monitored and estimated based on drivers' eye movements. Results of the study indicate that drivers' performance in stabilizing their vehicle was worse when the transition occurred as a result of the driver's lack of attention to the road. In these cases, drivers' visual attention continued to be erratic for up to 40 seconds after the transition of control.

Willemsen et al. (2015) explored the transition of control between vehicle and driver, implementing different strategies for the automated function to switch itself off in case of attentive or inattentive drivers and using a driving simulator to do so. Drivers' were presented with strategies that display warnings of transition and confirmation prompts at varying distances from the manual driving task requested of the participant. In some situations, participants were distracted by a secondary task. Differences between the tested conditions were small in both subjective and objective results, prompting repetition of the experiment with a larger population and a larger variance in experiment conditions.

In contrast to the mentioned literature, this study utilizes virtual immersive reality driving simulator to investigate factors (i.e. traffic , weather, lighting, multi-tasking) that affect drivers' willingness to give control to CAVs. In addition, this study looks at factors playing significant role on drivers' situational awareness when it comes to taking back control safely from CAVs when necessary . The main advantage of adapting virtual reality in our research is the ability to present and immerse the participant in a wider variety of scenarios such as rainy conditions. As mentioned earlier, virtual reality environment experiments have been conducted successfully in the past (Djavadian et al., 2019; Farooq et al., 2018; Kalatian et al., 2019) and studies have shown that participants are able to develop realistic spatial knowledge in the virtual reality environment that is comparable to actual physical environments (O'Neill, 1992; Ruddle et al., 1997; Tlauka & Wilson, 1996).

3. Methodology

To analyze the drivers' behaviour in giving and taking control, laboratory experiments are designed in virtual reality. This section presents methodology used to design the experiments and model travelers' behaviours.

3.1. Objectives

In this study, VIRE driving simulator Farooq et al. (2018), pre-experiment questionnaire, weighted NASA Task Load (NASA-TLX) index (Hart, 2006) and Detection Response Task (DRT) index (NEN-ISO 17488, 2016) are used to investigate under what conditions drivers are willing to give full control to CAVs and under what conditions are they able to safely take back control from CAVs. The aim of the VIRE driving simulation is to help answer the following questions:

1. What are the effects of traffic congestion (low, high), weather condition (clear, rainy), time of the day (day, night), and multi-tasking on willingness to give control to CAV and safely taking back control when necessary?
2. What is the effect of the order of the experiments in the choice of participants to give control to AV or not?
3. What is the effect of the order of the experiments on how well participants perform once they take back control from AVs?

Whereas the pre-experiment questionnaire is used to answer the following questions:

1. What are the effects of gender, age, driving experience, risk index, locus of control index and prior knowledge/experience of AV on drivers' willingness to give control to CAVs?
2. Will participants with different socio-demographic and personal behaviour have different acceptance of AVs under different traffic conditions/scenarios?
3. Will drivers who are familiar with AVs have more trust in AVs and as such, be less attentive when they are passenger and fail to take back control safely?

Lastly, the NASA-TLX index and DTR index are used to measure mental workload and situational awareness of drivers and the impact on safely taking back control from CAVs.

3.2. Dependent & Independent Variables

3.2.1. Dependent variables

As discussed earlier, the aim of this study is twofold: 1) to investigate factors that affect willingness of drivers to give control to CAVs and 2) to investigate factors that affect the ability of drivers to safely take back control from CAVs. As such, there are two independent variables that are set to binary:

1. Y_1 : Yes for giving control to CAV and no otherwise,
2. Y_2 : Yes for safely taking back control from CAV, and no otherwise.

3.2.2. Independent variables

Table 1 presents the independent variables used in this study. One of the key independent variables used is the Locus of Control index (Rotter, 1966) which as shown by Djavadian et al. (2019) has significant impact on the willingness of drivers to give control to CAVs or not. According to Rotter (1966), people are divided into two categories: a) those who believe there are external forces out of their control affecting their lives and b) those who believe they have control over events in their lives. The first group has external locus of control whereas the second group has internal locus of control. The higher the locus of control index means that the person has higher external locus of control. Djavadian et al. (2019) showed in their study that drivers with higher index of control are less willing to give control to CAVs. In this study the order in which experiments are presented to participants is also taken into account. For example, a participant may first experience taking back control from the CAV and may not perform safely, and in the next experiment where the participant has the option of giving control to the CAV may not do so due to the previous bad experience. Likewise, it is possible that a participant first experience being a passenger in a CAV and then in the next experiment, has to take back control from the CAV. Since the participant already has experience being driven by CAV, they may perform differently than a participant who goes through that same experiment without having experienced riding in a CAV.

Table 1: Independent Variables

User attributes	Travel attributes
Age	Congestion level
Gender	Weather condition
Education	Time of day (e.g. day, night)
Vision	Multi-tasking
Employment	
Driving experience	
Risk index	
Locus of control index	
Prior knowledge/experience of CAVs	
Order of experiments & previous choice	
Mental work load	

3.3. Choice Model

In this study, Binary Logit model is used to model willingness of drivers to give control to CAVs. Equation 1 presents the utility function for each condition.

$$U_{k,n} = \beta^T_{0,k} + \beta^T_{x,k} X_{k,n} + \beta^T_{z,k} Z_{k,n} + \epsilon_{x,k} \tag{1}$$

where:

$U_{k,n}$: expected utility of option $k \in K$ for participant $n \in N$. In the case of willingness to give control to CAVs the options are choosing to continue to drive manually or switch to CAV;

$X_{k,n}$: set of attributes related to option k;

$Z_{k,n}$: set of participant n attributes, e.g. socio-economic variables;

$\beta^T_{x,k}$, $\beta^T_{z,k}$: set of parameters corresponding to the attributes;

$\epsilon_{k,n}$: unobserved utility modeled as a Gumbel distribution.

The probability of each participant n giving control to CAV depending on β is shown by Equation 2. $k = 1$ represents giving control to CAV.

$$P_{1,n}|(\beta) = \frac{1}{1 + e^{-(\beta^T_{0,1} + \beta^T_{x,1} X_{1,n} + \beta^T_{z,1} Z_{1,n})}} \tag{2}$$

3.4. Experiment Setup

The laboratory experiment is divided into four sessions as shown below:

3.4.1. Information session

In the information session, the participants are provided with information about the experiment and are asked to fill out the pre-experiment questionnaire which consists of 4 sections as described below.

A ***Socio-economic/Demographic Attributes and Driving Experiences:*** Collects participants' age, gender, occupation, education level and income level. In addition, it collects information regarding real-life driving experiences in terms of years of experience.

B ***Personality Attributes:*** Collects participants' attitudes toward adventure and discovery through risk index (Khattak et al., 1995). A risk index is estimated for each subject, based on a scoring system. Alternative answers for each question are given a score from 0 to 4 in an ascending order; starting with 0 for option (i). The risk index, for each subject, is estimated to be the sum of scores of all questions. High risk index indicates a risk-seeking type of personality. Similar test was also used by Talaat (2008).

C ***Locus of Control:*** Collects subjects' internal versus external control reinforcement and provides information on personal perception of self-efficacy and control of a situation. The test is developed by Rotter (1966). Scores range from 0 to 13. A low score indicates an internal control while a high score indicates external control.

D ***Technology based Indicators:*** Collects information regarding participants familiarity with the concept of self-driving cars and factors affecting their choice of buying one in the future. In addition, it collects information regarding participants prior experience driving self-driving cars or being driven by one.

3.4.2. Learning session

The second session is the learning session where participants are familiarized with driving in the virtual reality environment. In addition the aim of this session was to reduce effect of virtual reality novelty on the choices of the participants.

3.4.3. Actual experiment

The actual experiment is conducted in the VIRE driving simulator. Every participant is asked to try 4 experiments, each lasting roughly 5 minutes. The experiments fall into two main categories: giving control to a CAV and taking back control from a CAV. For each category, different traffic conditions, weather conditions, lighting conditions (e.g. day, night) and multi-tasking options are tested. For both categories, users either drive or are driven along a 2km stretch of a multi-lane highway as shown in Figure 1.

1 **Giving control to CAV:** For this part of the experiment, the participants are asked to drive for approximately 5 minutes along a virtual highway. At any point, they are able to switch from manual driving to automated driving. To be able to switch to automated driving, the participants are asked to change lane to a dedicated CAV lane. The experiments vary in terms of traffic conditions, weather condition, lighting (day, night) and multi-tasking option. A pilot study was first conducted with participants not having the option of taking back control after they switched to autopilot, however after analysing participants' feedback it became apparent that option of taking back control played an important role in their decision to switch to autopilot. Hence, for the actual experiment participants are given the chance of switching back to manual after they switched to autopilot.

2 **Taking control back from CAV:** CAV systems contain a multitude of sensors that process collected data in order to make operational decisions and many of these sensors have limitations. For example, data collected by LIDAR can be distorted by falling rain and snow, while night time and limited visibility conditions can affect cameras (Kuhr et al., 2017). With this in mind, it is realistic to expect scenarios in which an CAV requests that the driver take control due to sensor disruption in safe functionality of the CAV. How situationally aware they are will affect their performance. For this part of the experiment, participants are driven by the CAV along a stretch of highway. At 1km from the start, the participant is prompted to take over control due to sensor failure or bad weather conditions. An auditory and visual warning is presented to the participant to bring back their focus on the road. Simultaneously, they approach an accident blocking their lane located approximately 200m after the initial warning is triggered. The warning is presented to allow participants enough time to either safely stop behind the accident or change lane and pass the accident. In order for the participant to take back the control from the CAV, they must pull a trigger found behind the steering wheel. Figure 1 presents the layout of this scenario. These experiments also vary in terms of traffic conditions, weather condition, lighting (day, night) and multi-tasking option.

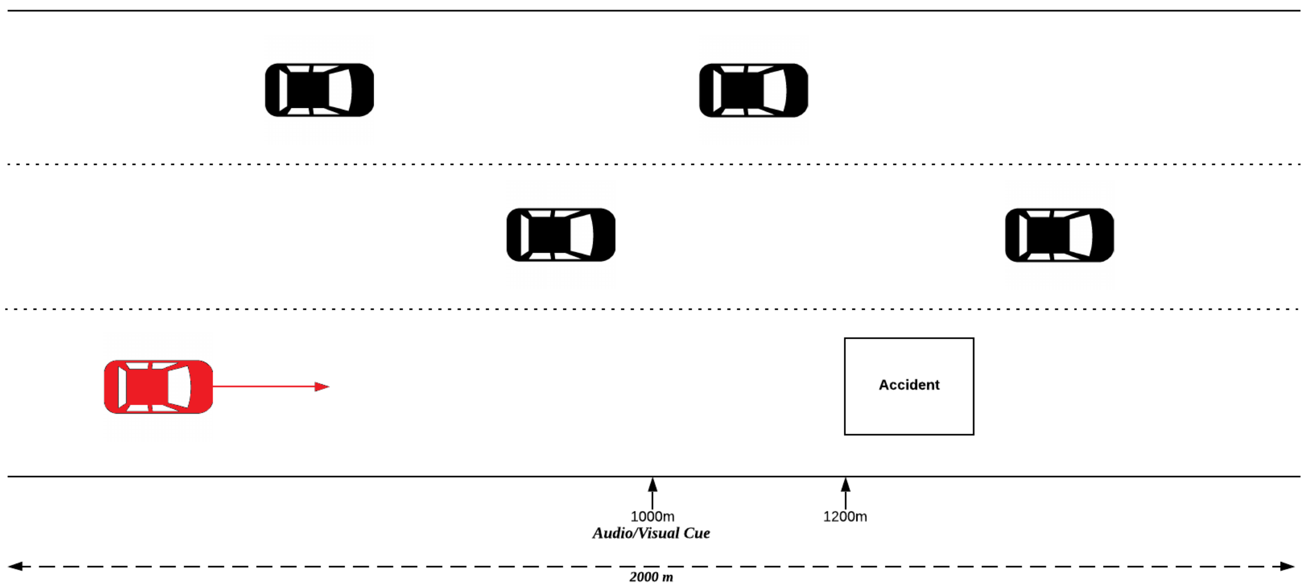


Figure 1: Taking control experiment setup

As shown in Figure 2 in total there are **32 scenarios (8 scenario per control type)** and out of these 32, we randomly assign 4 scenarios to each participant in such a way that all scenarios are repeated an equal number of times.

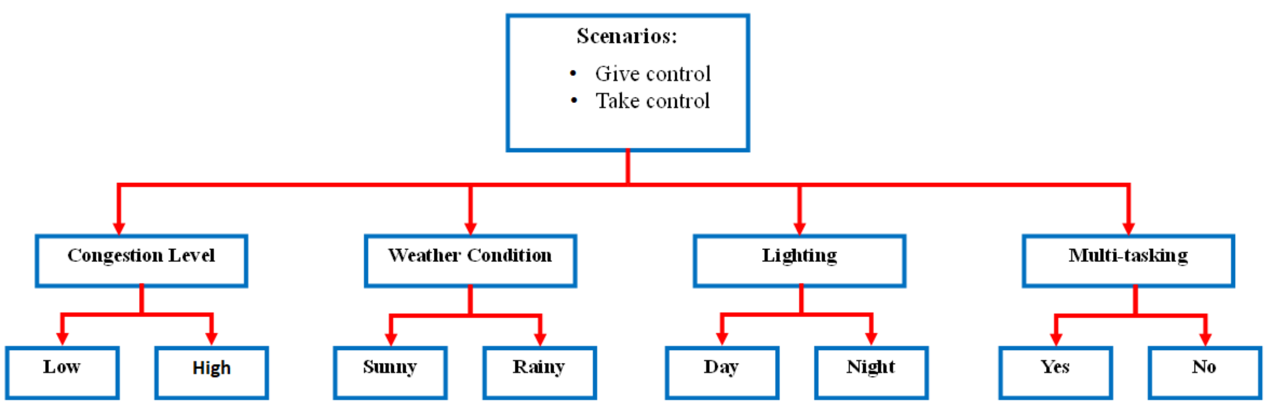


Figure 2: Scenarios.

Table 2 presents a description of each scenario, giving control to CAV (1-16), taking control back from CAV (17-32). In the label column: C (clear), R (rainy), D (day), N (night), H (high congestion), L (low congestion) and M (multi-tasking). If M is not present in the label then it means that multi-tasking is not available.

3.4.4. De-briefing

At the end of each experiment, participants are asked to fill out the NASA-TLX questionnaire rating their mental work load for the experiment they just performed. The NASA-TLX index (Hart,

Table 2: Scenarios

		Weather		Time		Multi-Tasking		Congestion	
Scenarios	**Label**	**Clear**	**Rainy**	**Day**	**Night**	**Yes**	**No**	**High**	**Low**
1,17	CDMH	x		x		x		x	
2,18	CDH	x		x			x	x	
3,19	CNMH	x			x	x		x	
4,20	CNH	x			x		x	x	
5,21	CDML	x		x		x			x
6,22	CDL	x		x			x		x
7,23	CNML	x			x	x			x
8,24	CNL	x			x		x		x
9,25	RDMH		x	x		x		x	
10,26	RDH		x	x			x	x	
11.27	RNMH		x		x	x		x	
12,28	RNH		x		x		x	x	
13,29	RDML		x	x		x			x
14,30	RDL		x	x			x		x
15,31	RNML		x		x	x			x
16,32	RNL		x		x		x		x

2006) is commonly used in aviation and automotive research to subjectively measure individual's mental workload on six dimensions: mental demand, temporal demand, physical demand, performance, effort and frustration. Stapel et al. (2019) also used the NASA-TLX index to measure mental workload of participants in interaction with AV. The NASA-TLX allows participants to score the relevance of each of these items, reducing variability between participants and task contexts. As stated by Miller (2001), the NASA-TLX is more reliable than physiological measures. Aside from using NASA-TLX to measure mental workload of participants subjectively, the DRT index is also used to measure cognitive load (NEN-ISO 17488, 2016) objectively. DRT measures the delay between stimulus and response. In this case the stimulus is the auditory and visual warning and response is pulling the trigger behind the steering wheel. We call this delay reaction time from this point on.

In the case of giving control to CAVs, participants are asked to explain what affected their choice. At the end of laboratory session, a short interview is conducted with the participants to receive their feedback regarding the experiment itself.

3.5. Virtual Immersive Reality Environment

The multi-lane stretch of highway was created in the open-source gaming engine Unity which VIRE (Farooq et al., 2018) is based on. To allow participants to drive in the virtual environment, VIRE is modified to include driving hardware such as a motion simulator, steering wheel and acceleration and braking pedals. VIRE is also modified such that it provides participants the option of fully giving control to AV en-route to their destination, allowing us to explore under what conditions (e.g. traffic condition, weather, time of day) users are more willing to give up control to AV. In addition, VIRE is further modified such a way that while being driven to their destinations by CAV participants are able to take over control from CAV in order to investigate their situational awareness. To investigate the effect of multi-tasking on the choices of drivers and their situational awareness, the option to multi-task is also introduced such that the participant riding CAV can read a virtual newspaper or play a maze game on a virtual mobile phone. Moreover, different traffic conditions (low, high), different weather conditions (clear, rainy) and different lighting (day, night) are added to VIRE to measure their impact on the choices of drivers in giving control to CAVs and taking control back safely. During experiments, the following hardware was used:

. Oculus Rift with motion and touch sensors

. Thrustmaster T150 Force Feedback Racing Wheel and pedals,

. Intel Core i7-8700 CPU,

. DOFReality Consumer H3 Platform,

. NVIDIA GeForce RTX 2080

Figure 3 presents the snapshots of the virtual reality setup for the two travel options. Figure 3a is the snapshot of taking control away from CAV scenario where as Figure 3b is the snapshot of giving control to CAV and multi-tasking scenario. Figure 3a presents sunny weather conditions where as Figure 3d presents rainy day scenario.

3.6. Results & Discussion

This section provides results and analysis of the pilot study tested with graduated students and employees from Ryerson University and University of Toronto. The following information is collected from the laboratory experiment:

Data that collected from the pre-experiment questionnaire

- socio-demographic characteristics (e.g. age, gender, education, etc.)
- driving experience
- risk index
- locus of control index
- knowledge/experience of CAV/AVs

Data collected from the VR simulator for each scenario

- participant's choice (switching to CAV or not)
- time of switching to CAV from manual driving
- reaction time to visual or auditory trigger
- force on the brake pedal after they take back control
- speed before and after taking cover
- performance after taking back control (safe stop/lane change or not?)
- distance to the object at stop position

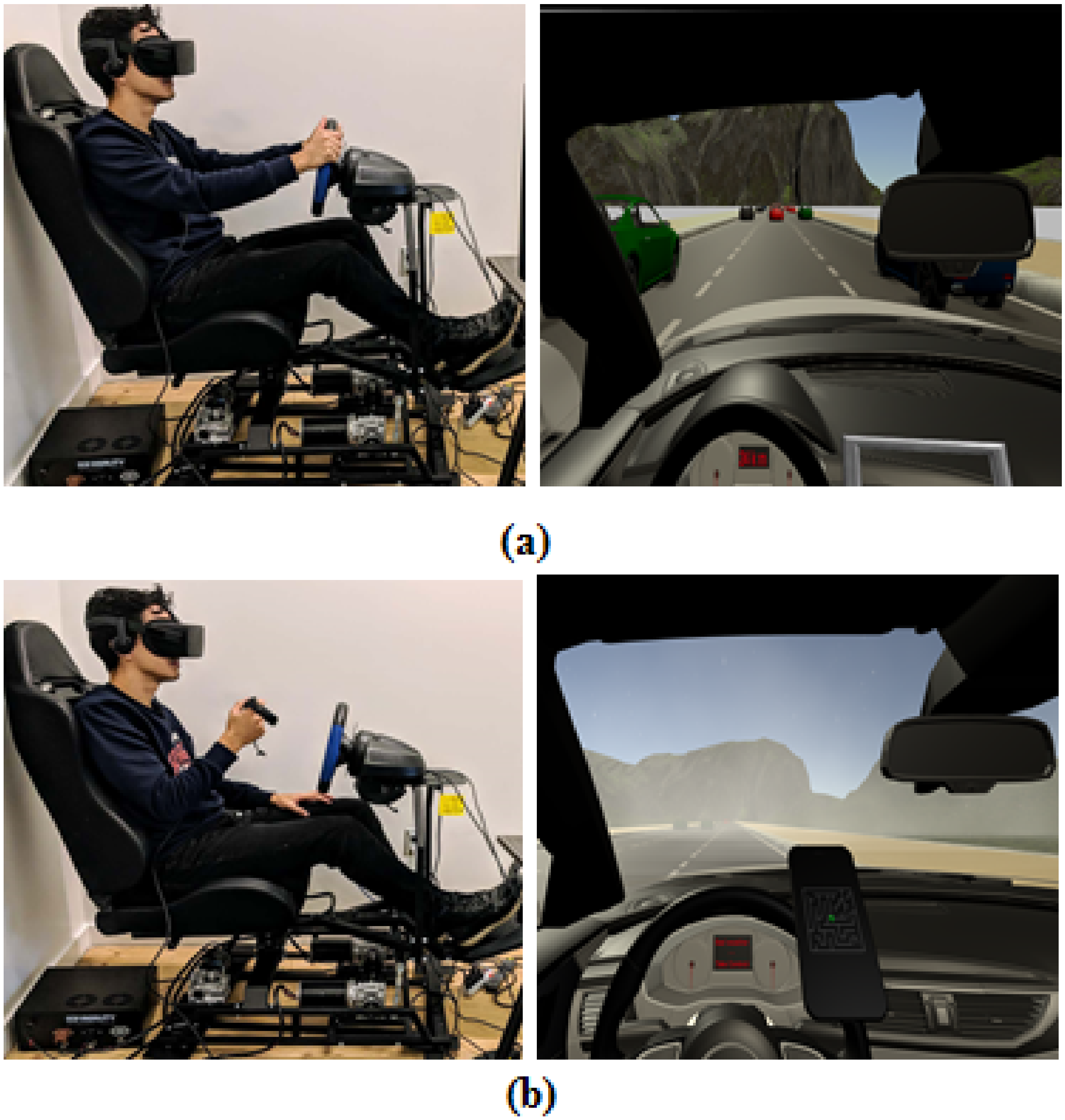


Figure 3: Participant in VIRE driving simulator.

- time to full stop/ lane change
- head position before the occurrence of the incident

Data collected from the post-experiment questionnaire

- workload from NASA-TLX
- reason behind participants choices

3.7. Pre-experiment Questionnaire

3.7.1. Socio-demographic characteristics of participants

A brief description of our participants is presented in Table 3. As can be seen from Table 3 there is a heterogeneity among participants.

Table 3: Socio-demographic characteristics of the participants

	Number of Participants, by Age (years)						
Characteristics	18-24	25-29	30-39	40-49	50-59	60+	Total
All Participants	27	15	15	4	2	2	65
Gender							
Female	7	5	8	2	1	2	25(38%)
Male	20	10	7	2	1	0	40(62%)
Occupation							
Student	25	13	6	0	0	0	44(68%)
Employee	2	2	9	4	2	2	21(32%)
Education							
Bachelor	3	2	2	1	0	2	10(15%)
Masters	2	9	3	0	1	0	15(23%)
Doctorate	0	3	6	3	1	0	13(20%)
Uni/College	21	1	4	0	0	0	26(40%)
Highschool	1	0	0	0	0	0	1(2%)
Driving experience (years)							
Not at all	3	0	0	0	0	0	3(5%)
< 2	8	1	1	0	0	0	10(15%)
2-5	11	2	1	0	0	0	14(22%)
5-10	5	7	4	1	0	0	17(26%)
> 10	0	5	9	3	2	2	21(32%)

3.7.2. Perception towards AV/CAV

As part of pre-experiment questionnaire, participants were asked questions regarding their prior knowledge of and experience with AV/CAVs, and as shown in Table 4, 90 % of the participants were familiar with the concept of AV while 4 % of them had experience riding a AV/CAV shuttle at a technology fair. Aside from their knowledge of AV/CAVs, participants were asked which factors affect their choice of buying AV/CAV positively and negatively. Figure 4 presents factors play an important role in their willingness to purchase/ride an AV/CAV. As can be seen from Figure 4a, the three main factors negatively affecting participants willingness to buy an AV/CAV in descending order are concerns about safety & equipment failure, hacking, and giving full control to AV/CAV. From Figure 4b, it can be seen that participants would purchase AV/CAV because of higher safety, less congestion, and less time spent on finding a parking space. As shown by Figure 4c, participants are more willing to give ride (give control to) AV/CAV mostly in heavy congestion, on highways, and on unfamiliar networks.

Table 4: Participants' prior knowledge/ experience of AV/CAV

	Results	
Technology based indicators	**% Yes**	**% No**
Prior familiarity with the concept of AV	90.00	10.00
Prior familiarity with concept of CAV	60.00	40.00
Experienced being driven by an AV	4.00	96.00

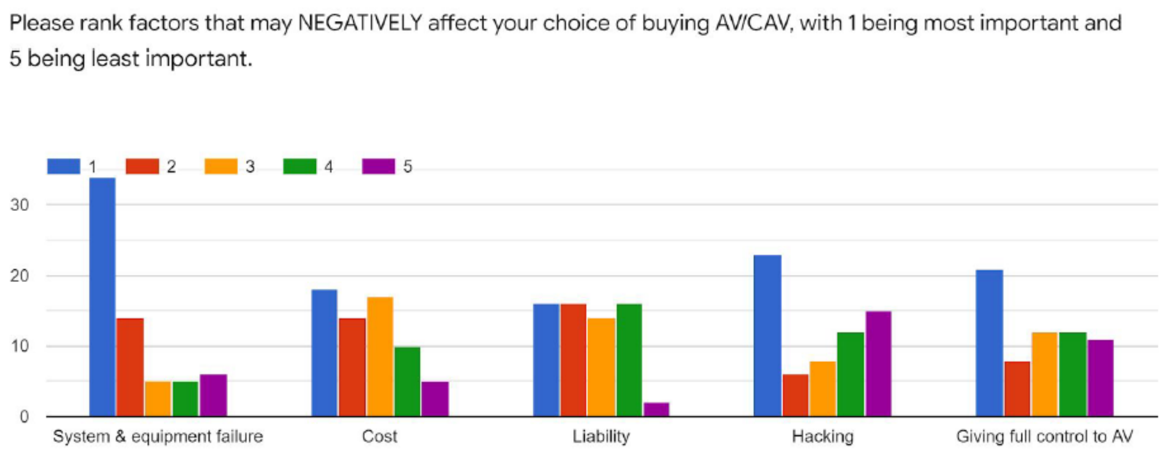
3.8. VIRE Driving Simulator Results

Figure 5a shows the percentage of times participants were willing to give control to CAV and Figure 5b presents the percentage of times participants were able to safely take back control from CAV. Table 5 provides summary of Figure 5. Looking at Figure 5a and Table 5 it can be seen that participants 12.77 % of times were more willing to give control to CAV en-route when multi-tasking option was available as opposed to when the option wasn't available. This results is inline with the results of questionnaire and the results of VIRE experiment conducted by Djavadian et al. (2019). On the other hand it can be observed from both Figure 5b and Table 5 that multi-tasking had significant negative impact on participants' ability to safely take control back from CAV when it was necessary to do so. On average participants failed to safely take back control from CAV 35.94% of times more more when multi-tasking was available as opposed to when it wasn't available. The reason for this substantial drop in participants ability to take back control when multi-tasking was able was due to the fact that they were distracted hence it took them longer time to react and take back control, this will be discussed in more details in the next section. In fact, recently there was an accident involving Tesla autopilot where the driver was distracted playing a game on his phone and failed to safely take back control of the car when he was prompted (News, 2020).

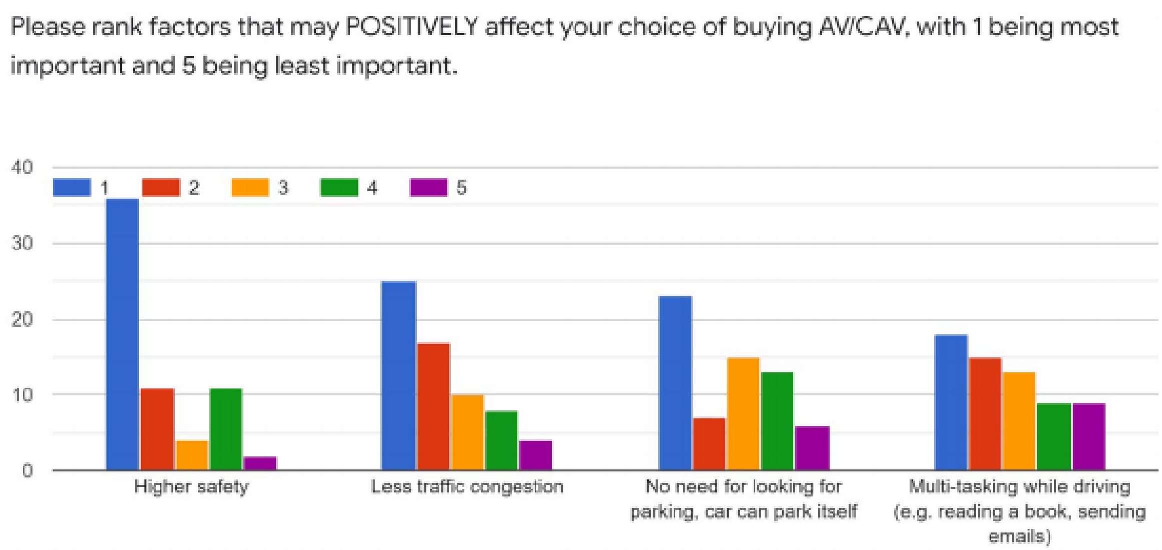
Looking at Figure 5a and Table 5 it can be seen that participants 11.57% of the times were more willing to give control to CAV when the sky was clear as opposed to when it was rainy. Based on the results of the de-briefing questionnaire, poor visibility in the rain was the main contributor to this phenomenon. In addition, on the de-briefing questionnaire participants mentioned that they enjoyed giving control to CAV when sky was clear because they could enjoy the scenery. When it came to taking back control safely from CAV, surprisingly participants were 8.40 % less successful under clear sky. This might be due to the fact that when sky was clear they were less vigilant. As reported by participants in de-briefing questionnaire even when multi-tasking was available when it was rainy and it was night time, they preferred to keep their eyes on the road.

Aside from multi-tasking option and weather condition, traffic condition as shown in Figure 5a and Table 5 also played an important role on the choices of participant in giving control to CAV en-route. It can be seen that under low traffic congestion participants gave control to CAV 10.83 % of times more in contrast to when the congestion level was high. As discussed on the de-briefing questionnaire participants were more willing to switch to CAV when traffic was low because they liked being driven on an open road and enjoying the scenery. It can be seen that observed results from VIRE pre-experiment questionnaire (Figure 4c where participants mentioned that they are more willing to give control to CAV when it is congested, this shows the difference between having visual image (VIRE) as opposed to just mental image (online SP). There were still some participants who gave control to CAV when there was high congestion because it reduced the hassle of stop-and-go for them. It should be noted that in this study the CAV was only traveling on single lane with no lane changing and taking over capability, as such when there was congestion the CAV would get stuck behind the leading vehicle, and this was one reason that participants didn't enjoy being driven by CAV for too long. It was observed that participants would put the car on auto-pilot and when there was congestion they would take control back switch lane, overtake the leading car and then would switch back to auto-pilot. It could be possible that in the future when CAVs have the capability of switching lane and taking over other vehicles, drivers would be willing to give control to CAV even when there is high congestion level.

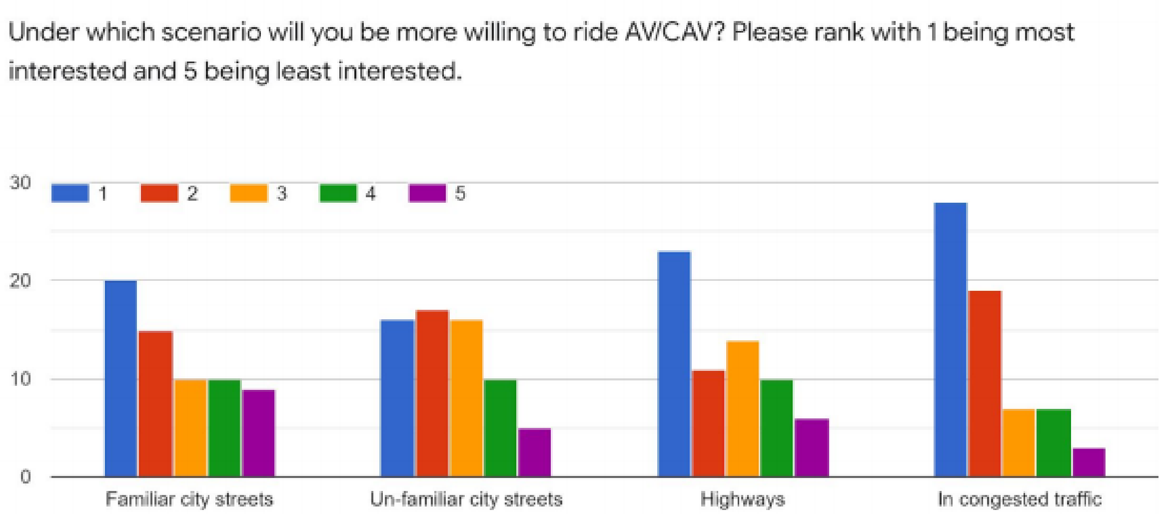
It is worth mentioning that traffic condition as shown in Figure 5b and Table 5 had a very minuscule effect on the performance of participants when it came to safely taking control back from CAV. The reason for the aforementioned phenomenon is that ability of drivers to safely take back control depends highly on factors affecting their reaction time and their visibility such as multi-



(a)



(b)



(c)

Figure 4: Factors affecting willingness to buy and ride AV/CAV

tasking, weather condition and time of the day. When it was night time, as observable from Figure 5 and Table 5, participants were 5.50% of the times more eager to switch to auto-pilot and give control to CAV but they were 8.51 % times less successful to take control back successful at night due to visibility.

Before the start of this experiment a pilot study was conducted with 20 participants where they mentioned that they would have given control to CAV more often if the trip was longer and if they had the option of taking back the control after switching to CAV. The experiments were adjusted accordingly and the results showed that aside from weather condition, congestion level, time of the day and option of multi-tasking , factors such as trip length and ability to take back control when desired played important role on choices of participants.

In this study as discussed in the methodology section, 4 experiments were randomly assigned to each participants and the effect of previous scenarios were also investigated on the choices of the participants. The results showed that order of experiments to some extend had affected the choices of participants, for example if a participant in their first scenario was unsuccessful to take back control safely from CAV, in their second scenario they he/she prevented themselves from giving control to CAV. On the other hand a positive take away experience resulted in higher willingness to switch to auto-pilot next time that they had the chance. This shows the effect of experience on the choices of drivers and this is something that I can hardly be measured using traditional online or paper based SP. Similarly, results showed that experiment orders in the case of take-away control from CAV also played a significant role on the performance of the participants. Those participants who went through two or more take-away scenarios their attentiveness and performance improved in subsequent experiments. For example, those who forgot to pull the trigger behind the steering wheel remembered to pull it in subsequent experiments. This shows once again the importance of using virtual reality not only to test the behaviour of drivers with respect to AV/CAV but also as a learning tool since in reality it is not possible to replicate accidents repeatedly in a safe manner. Also, repetition improved vigilance of the participant, once they were aware that auto-pilot can fail at times, they paid closer attention to the road, increasing their situational awareness and reducing their reaction time.

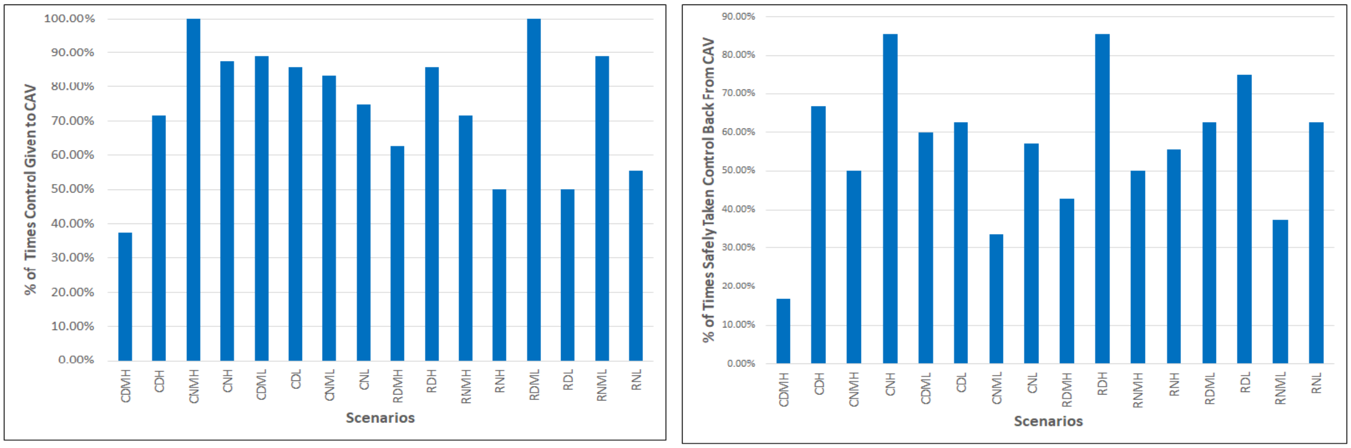
An interesting observation from Figure 5 is that scenarios that participants were more willing to give control to CAV where the same scenarios that they were less successful to take back control safely when necessary. This should be taken into consideration when developing policy and designing CAVs.

Table 5: Factors affecting drivers' willingness to give control to and take away control from CAVs

	% differences	
Variables	Giving Control	Safely taking control back
Multi-tasking vs. No multi-tasking	12.77	-35.94
Clear Sky vs. Rainy	11.57	-8.40
Low vs. High congestion	10.83	-0.60
Night vs. Day	5.15	-8.51

3.9. Mental Workload

Figure 6 presents the breakdown of the composition of weighted mental workload score. It should be noted that participants were asked to rank the mental workload from the moment they



(a) Giving control to CAV

(b) Taking control back from CAV

Figure 5: % of times a) Giving control to CAV , b) Safely taking control back from CAV

received the sensor failure warning and prompted to take back control till the moment they safely passed the accident and finished traveling the highway. The overall mental workload calculated using NASA-TLX questionnaire was 50.60 (scale 0-100). As can be seen from Figure 6, temporal demand, frustration and mental demand contributed the most to the overall workload and as a result to the performance of the participants in taking back the control from CAV and safely passing the accident. Temporal demand is associated with time pressure for performing a task, and mental demand is associated with amount of thinking required to perform a task successfully and frustration is the amount of stress participant felt in doing the task.

Figure 7 presents average mental workload and reaction time for each individual scenario whereas Table 6 shows statistical summary for mental workload and reaction time. The average reaction-time was 4.04 seconds (the delay between when warning was presented to the participant and when the participant pulled the trigger to switch to manual control). The lowest reaction-time was 1.83 seconds associated with scenario CDL (Figure 7b due to the fact that option of multi-tasking was not available therefore participants were paying closer attention to the road. In addition it was day time and clear sky as such participants were more vigilant. Not only scenario CDL had lowest reaction time but it also had the least overall mental workload (Figure 7a associated with it for the aforementioned reasons. Second and third lowest reaction times (Figure 7b) were associated with scenarios RNL and RNH for the same reason that multi-tasking was not available and participants were focusing on the road. However, from Figure 7a it can be noticed that although these two scenarios had low reaction time, they had high overall mental workload this is due the fact that it was rainy and night time so participants had lower visibility and found the task stressful even though they were paying more attention to the road. The discrepancy between reaction time and overall mental workload level shows the difference between how subjectively participants rated their mental workload and how it was objectively measured using DRT (reaction time). There is clearly disassociation between them. This seems to be the general trend for other scenarios as well, the ones with multi-tasking available had higher reaction time than the ones that didn't have multi-tasking option available .

3.10. Binary Logit Model Results

The initial results of the binary Logit model estimation based on the data gathered from the pilot study are presented in this section. The parameter values are not finalized, but provide us with

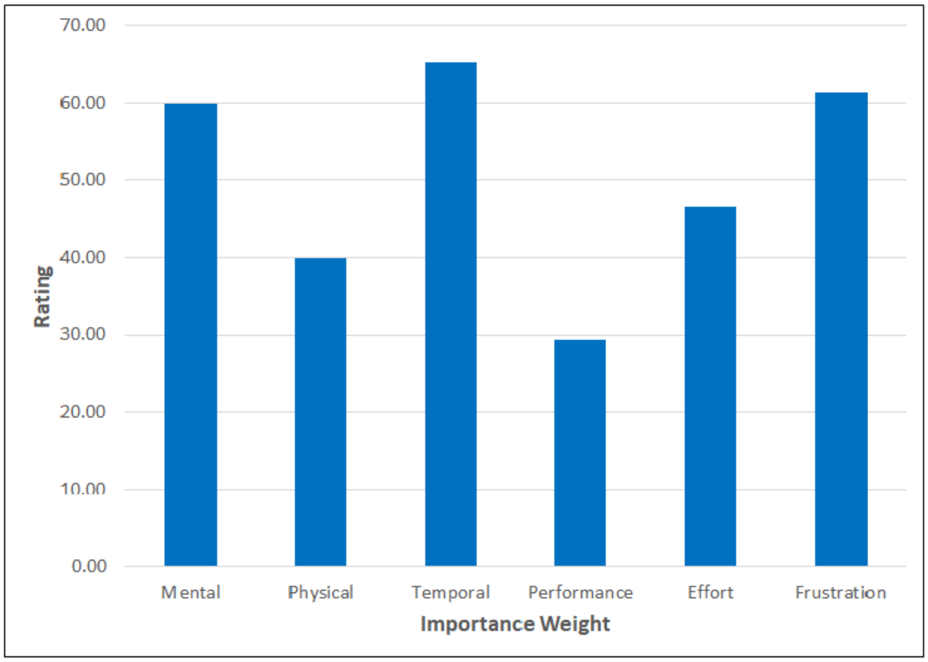
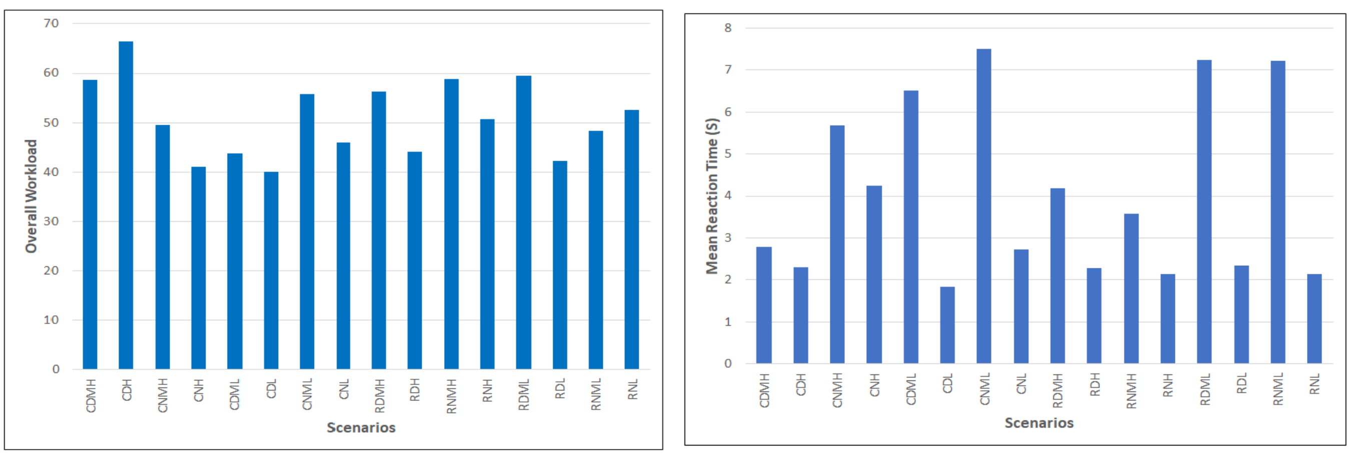


Figure 6: Composition of weighted mental workload score.



(a) Mental workload (NASA-TLX)

(b) Reaction time (DRT)

Figure 7: a) Mental workload vs. b) reaction time

Table 6: Descriptive statistics for reaction time & mental workload

Stats.	Reaction time (sec)	Mental workload (out of 100)
Mean	4.04	50.93
Standard deviation	2.09	19.78
Minimum	1.83	9.33
Maximum	7.50	92.33

an idea of what variables had the most impact on the choices of participants when it came to the preference of giving control to CAV en-route.

3.10.1. Give-away experiment

Table 7 presents the results of binary Logit model for the give-away experiments. As can be seen, the two main factors were heavy congestion when sky was clear and rain. With respect to rain, if the weather condition was rainy the variable was 1 and otherwise 0. As discussed before and as shown in Figure 5a, more participants gave control to CAV en-route under rainy weather condition which explains the positive sign of rain variable. These results are in-line with the de-briefing questionnaire where majority of participants noted that they were more inclined to give control to CAV under bad weather condition because of poor visibility. In regard to the variable clearsky-heavycongestion, when the sky was clear and the traffic congestion was heavy the variable was 1 and 0 otherwise. As can be seen from Table 7 and Figure 5a , the participants were less willing to give control to CAV when the weather condition was good, unless there was a heavy congestion. This explains the positive sign of the variable clearsky-heavycongestion. On the de-briefing questionnaire participants reported that when it was day light and light traffic condition they enjoyed driving but in heavy congestion they would rather give away control to CAV due to stop & go nature of traffic.

Table 7: Preliminary Binary Logit Model estimation results

Variables	Estimate	t-stat
ClearSky-HeavyCongestion (1,0)	1.40	2.10
Rain (1,0)	1.10	1.71
# of Observations	36	
# of parameters tested	2	
Likelihood ratio test	8.401	
Adjusted Rho-square	0.088	

4. Concluding Discussion

In this study, we designed and conducted a stated preference experiment employing virtual immersive reality environment simulator to investigate the factors that affect the willingness of drivers to give control to CAV en-route and similarly the factors that affect their mental workload and situational awareness when it comes to taking control safely back from CAV when required.

This study was divided into four sections: pre-experiment questionnaire, learning session, virtual reality experiment and de-briefing questionnaire which included NASA-TLX questions to evaluate participants mental workload. The pre-experiment questionnaire was used to collect socio-demographic characteristics of participants and their familiarity and perception of CAV. The results obtained showed that almost all the participants were familiar to some extend with the concept of CAV. The fear of equipment failure, liability, and giving full control were reported as three main factors negatively affecting their decision of buying CAV in the future. With the same token, they reported that in general they think CAV will make driving safer, less congested and reduce the need for finding parking space. Based on the results of the questionnaire, participants were more willing to give control to CAV under heavy traffic congestion, while driving on highways and while driving on unfamiliar networks. The purpose of the learning session was to familiarized participants with driving in virtual reality and at the same time reduce the effect of VIRE novelty on the choices of the participants.

Two different sets of experiments were implemented in VIRE. In the first set of experiments, participants were asked to drive on a 2km stretch of multi-lane highway with the option of giving control to CAV anytime en-route (taking control back when desired). In the second set of experiments, participants were being driven on the same stretch of highway by CAV, however at some point en-route due to sensor failure they were asked to take back control and safely pass the accident ahead. Auditory and visual warnings were used to bring back the focus of the participants to driving. Different weather, traffic and lighting conditions were tested for both set of experiments. While being driven by CAV, participants were also provided the option of multi-tasking (i.e. playing game on the smartphone). The results from the VIRE experiment contradicted with the ones from the pre-experiment questionnaire in the sense that VIRE results showed that participants were more willing to give control to CAV en-route when the congestion was low as opposed to when it was highly congested (pre-experiment results). The aforementioned discrepancy shows the value of having visual image and immersive experience as opposed to just mental image provided by traditional SP surveys. Based on participants' feedback on the de-briefing questionnaire, they enjoyed giving control to CAV when it was low congestion because they liked being driven on an open road instead of being stuck behind traffic. Those who gave control when congestion level was high mentioned that they did it because switching to CAV took away the hassle of stop and go for them.

The results from the VIRE experiment also showed that bad weather conditions and poor visibility played an important role on the decision of participants to give control to CAV. Participants were less inclined to give control to CAV when it was rainy, mentioning that they didn't trust CAV. In line with the study conducted by Djavadian et al. (2019), it was shown in this study that multi-tasking also played a significant role in giving control en-route, with participants switching to auto-pilot 35% of the times more when multi-tasking option was available. Although it is worth mentioning that some participants they refrained themselves from using multi-tasking when it was rainy , citing that they preferred instead to keep their eyes on the road.

In the case of taking back control from CAV, the average mental workload calculated using NASA-TLX index was 50.60 (scale 0-100) with temporal demand, mental demand and frustration having higher weights. Using detection response task technique, in this case reaction time to the auditory and visual warning the average reaction time was 4.04 seconds. The reaction time was lower and success rate was higher under scenarios where congestion level was low and multi-tasking was not available suggesting that multi-tasking and congestion level playing major role on drivers' situational awareness. There was the discrepancy between the subjective workload (NASA-TLX) results and the objective one (DRT). In general scenarios that had lowest reaction time they had higher workload (rainy night and no multi-tasking)

There are several directions that can be taken in future studies. First and foremost, the laboratory experiment will be conducted with larger and more heterogeneous sample size. The results from debriefing questionnaire showed that participants were more willing to give control to CAV en-route if the trip was longer and if they had the option of taking control back whenever they wanted. In general, the participants were split with regards to their decision to trust CAV at night and rain. In the future study, we will look into extending trip length and providing the option of taking back control once the control is giving to CAV. Although auditory and visual warnings were provided to participants, some participants were not able to successfully take over the control from CAV because they forgot to pull the trigger to assume control and instead they intuitively pressed the brake pedal. They noted that aside from warnings, they would prefer to receive clear instructions as what to do when they have to take back control. In future studies, the effect of giving clear directions will be examined. In this study, NASA-TLX was used to subjectively measure mental workload and situational awareness. In the future, Galvanic Skin Response (GSR) sensors will be used to measure emotional arousal of the participants objectively when they have to take control from CAV.

The project results will be of interest to car manufacturers, to design CAVs in a way that will have maximum safety and driver acceptance, increasing market share. Also, the results will be of benefit to traffic information providers, traffic management centers, city planners, and municipalities, allowing them to target the right audience and apply traffic management strategies using CAVs in situations that will result in higher acceptance and efficient use of transportation system. In general, participants were more successful in taking control back safely in subsequent trials as opposed to their first trial. In fact, those who experienced the take control scenario were more vigilant in their subsequent experiments, even in the give control scenario. This points to the idea that knowledge about CAVs is not sufficient and that consumers need to have the opportunity to experience being driven by CAV and taught how to take back control safely. This can be done by providing pilot studies using virtual reality or test CAVs.

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References

Alfaseeh, L., Djavadian, S., & Farooq, B. (2019). Impact of Distributed Routing of Intelligent Vehicles on Urban Traffic. In *2018 IEEE International Smart Cities Conference, ISC2 2018*. doi:10.1109/ISC2.2018.8656941.

Becker, F., & Axhausen, K. W. (2017). Literature review on surveys investigating the acceptance of automated vehicles. *Transportation*, . doi:10.1007/s11116-017-9808-9.

Djavadian, S., Farooq, B., Vasquez, R., & Yip, G. (2019). Virtual Immersive Reality based Analysis of Behavioral Responses in Connected and Autonomous Vehicle Environment. In A. Goulias, K. Davis (Ed.), *Mapping the Travel Behavior Genome* chapter 27. Elsevier.

Farooq, B., Cherchi, E., & Sobhani, A. (2018). Virtual immersive reality for stated preference travel behavior experiments: A case study of autonomous vehicles on urban roads. *Transportation Research Record*, . doi:10.1177/0361198118776810.

Farooq, B., & Djavadian, S. (2019). Distributed Traffic Management System with Dynamic End-to-End Routing. U.S. Provisional Pat. Ser. No. 62/865,725.

Hart, S. G. (2006). Nasa-Task Load Index (NASA-TLX); 20 Years Later. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, . doi:10.1177/154193120605000909.

Hirose, T., Kitabayashi, D., & Kubota, H. (2015). Driving Characteristics of Drivers in a State of Low Alertness when an Autonomous System Changes from Autonomous Driving to Manual Driving. In *SAE Technical Paper Series*. doi:10.4271/2015-01-1407.

Kalatian, A., Sobhani, A., & Farooq, B. (2019). Analysis of distracted pedestrians' waiting time: Head-mounted immersive virtual reality application. *arXiv preprint arXiv:1903.11812*, .

Khattak, A., Schofer, J., & Koppelman, F. (1995). Factors Influencing Commuters' En Route Diversion Behavior in Response to Delay. *Transportation Research Record: Journal of the Transportation Research Board*, *1318*, 125–135.

Kuhr, J., Juri, N. R., Bhat, C., Archer, J., Duthie, J., Varela, E., & Zalawadia, M. (2017). Travel Modeling in an Era of Connected and Automated Transportation Systems: An Investigation in the Dallas-Fort Worth Area Research. *Data-Supported Transportation Operations & Planning Center (D-STOP): A Tier 1 USDOT University Transportation Center at The University of Texas at Austin D*, .

Merat, N., Jamson, A. H., Lai, F. C., Daly, M., & Carsten, O. M. (2014). Transition to manual: Driver behaviour when resuming control from a highly automated vehicle. *Transportation Research Part F: Traffic Psychology and Behaviour*, . doi:10.1016/j.trf.2014.09.005.

Miller, S. (2001). *Literature Review: Workload measures*. Technical Report National Advaned Driving Simulator Iowa City.

NEN-ISO 17488 (2016). *DRT for assessing attentional effects of cognitive load*. Technical Report Nederlands Normalisatie Instituut. URL: https://www.iso.org/obp/ui/{#}iso:std:iso:17488:ed-1:v1:en.

News, B. (2020). Tesla Autopilot crash driver 'was playing video game. URL: https://www.bbc.com/news/technology-51645566.

O'Neill, M. J. (1992). Effects of familiarity and plan complexity on wayfinding in simulated buildings. *Journal of Environmental Psychology*, *12*, 319–327.

Rotter, J. B. (1966). Generalized expectancies for internal versus external control of reinforcement. doi:10.1037/h0092976.

Ruddle, R. A., Payne, S. J., & Jones, D. M. (1997). Navigating buildings in" desk-top" virtual environments: Experimental investigations using extended navigational experience. *Journal of Experimental Psychology: Applied*, *3*, 143.

Stapel, J., Mullakkal-babu, F. A., & Happee, R. (2017). Driver Behavior and Workload in an On-road Automated Vehicle. *Proceedings of the Road Safety and Simulation Conference*, .

Stapel, J., Mullakkal-Babu, F. A., & Happee, R. (2019). Automated driving reduces perceived workload, but monitoring causes higher cognitive load than manual driving. *Transportation Research Part F: Traffic Psychology and Behaviour*, . doi:10.1016/j.trf.2018.11.006.

Talaat, H. (2008). *Decision Field theoretical analysis and modelling of dynamic route choice deliberation process*. Ph.d. dissertation University of Toronto.

Tlauka, M., & Wilson, P. N. (1996). Orientation-free representations from navigation through a computer-simulated environment. *Environment and Behavior*, *28*, 647–664.

Willemsen, D., Stuiver, A., & Hogema, J. (2015). Automated driving functions giving control back to the driver: a simulator study on driver state dependent strategies. In *24th international technical conference on th enhanced safety of vehicles*.