An Exploration of Predictors of Adoption and Use of In-vehicle Voice Control Systems

by

Joyita Chakraborty

A thesis submitted in conformity with the requirements
for the degree of Master of Applied Science

Department of Mechanical and Industrial Engineering
University of Toronto

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2020

Abstract

In-vehicle voice control systems (VCS) have the potential to reduce driver distraction and thereby, increase road safety. However, little is known about factors that influence their adoption and use. This thesis examines VCS usage patterns and uses the Technology Acceptance Model framework to explore predictors of VCS use. A survey study (N = 198), which was informed by the findings of a focus group study (N = 9), was conducted and structural equal modelling was used to build predictive models. While multiple constructs predicted drivers' attitude toward VCS, which in turn projected their use, the strongest predictors were perceived ease-of-use and perceived usefulness toward accomplishing tasks when compared to visual-manual interactions. A driving simulator study was designed to examine the role of context and impact of reliability notifications on VCS acceptance and driving performance, in the presence of background noise, but was not carried out due to the COVID-19 pandemic.

Acknowledgments

I am grateful to my supervisor Professor Birsen Donmez for her guidance and support. Throughout my MASc, she mentored me in a balanced way that allowed for autonomy while offering me various opportunities to expand my skillset. I would especially like to thank her for always being open to discussing and exploring the ideas that I brought forward and for being understanding of the unusual and challenging circumstances that I found myself in during my master's.

I would like to thank my research collaborators: Suzan Ayas, Sam Fang, and Michelle Ji for helping out with the logistics of and taking notes during the focus group study, and Nicholas Tseng for helping me finalize the survey and run in on Mechanical Turk.

My labmates from the Human Factors and Applied Statistics lab have been an invaluable source of support during my time at UofT. A big thank you to past and present members who generously took the time out of their busy schedules to review my work and provide feedback. I would especially like to thank Dengbo He for all his help with the driving simulator and Braden Hansma for his guidance on using structural equation models. A big thank you to Dina Kanaan, Davide Gentile, and Julian Potvin-Bernal from PIEDlab for volunteering their time to be my "VCS operators" for the simulator study. Special thanks to former HFAST members Martina Risteska, Samantha Hopkins, Canmanie Ponnambalam, and Wayne Giang for their friendship and support.

I would also like to thank my friends and officemates Adam Reiner, Fahimeh Rajabiyazdi, and Catherine Solis for being excellent sounding boards, great sources of moral and academic support, and for always being open to a coffee or lunch outing.

Finally, I would not have been able to do this without the support of those nearest and dearest to me. A heartfelt thank you to my sister, Sonhita Chakraborty, and my parents, Sharmistha and Pijush Chakraborty, for everything. I am immeasurably grateful to have been born into your family. Last, but far from least, a huge thank you to my friend and partner, Matthew Smith, for all his support during this time, including lending some of the most formidable language skills I have ever encountered to help finetune this thesis.

Table of Contents

List of Tables

List of Figures

List of Appendices

Chapter 1

1.0 Introduction

1.1 Motivation

As more technology finds its way into the vehicle's environment - whether it be through systems built into the car, or devices that accompany the driver - the number of elements that compete for the driver's visual, manual, and cognitive resources increases. This raises the risk of distracted driving which, in turn, negatively impacts road safety. According to the National Highway Traffic Safety Administration (NHTSA), in the US, 2,841 people were killed in motor vehicle crashes involving distraction in 2018 (National Highway Traffic Safety Administration). The numbers are similar in the years preceding; in 2017 (National Center for Statistics and Analysis, 2019) and 2016 (National Center for Statistics and Analysis, 2018), there were 2,935 and 3,157 fatal crashes respectively (9% of all fatal crashes in both cases) on US roadways which involved distracted driving.

Several definitions exist for driver distraction; one concise definition is the misallocation of attention from driving to a non-driving task or source of information (Smiley, 2005). These tasks include a broad range of activities such as grooming, eating, conversing with a passenger, talking on a hand-held or hands-free device, interacting with in-vehicle information systems, to name a few, and they do not affect the driver's performance equally. As driving is primarily a visual-manual activity, tasks that take drivers' eyes away from the road and hands away from the steering wheel, such as texting, are particularly dangerous. In contrast, auditory-vocal interactions, while still tapping into drivers' attentional resources, do not interfere as much with the primary task of driving, and therefore pose less of a risk to driving safety. A study by Dingus et al. (2016) that analyzed naturalistic driving data collected from the Strategic Highway Research Program 2 (SHRP2) found that texting on a cell phone increased crash risk by a factor of 6.1, whereas talking on a handheld cell phone instead of texting increased crash risk by a factor of 2.2. Peissner & Doebler (2011) showed that when compared with visual-manual interactions, voice interactions resulted in better driving performance, and a reduction in the occurrence of safety critical events. This promise of increased safety, along with the advancement of technology and increased adoption of voice assistants in non-driving contexts, has driven the proliferation of in-vehicle voice control systems.

Voice control systems (VCS) were first introduced in vehicles nearly two decades ago (Heisterkamp, 2001), and since then they have steadily become commonplace in automobiles. According to Guidehouse Insights (Guidehouse Insights, 2019), VCS are projected to be embedded in nearly 90% of new vehicles sold globally by 2028. VCS are complex voice activated systems that, according to Walker et al. (2017), "allow drivers to talk to in-vehicle devices in order to control operation". These systems also have been referred to as voice command systems (Reimer et al., 2014), automotive speech interfaces (Lo & Green, 2013), and voice user interfaces (Jung et al., 2020). VCS take the user's spoken utterances as input and respond by providing visual and/or visual feedback, taking an action, or a combination thereof. According to Jenness et al. (2016), VCS are typically able to access a wide array of applications including those that are "fully integrated into the vehicle's on-board computer systems", hosted on cloud-based systems and require an internet connection, as well as those that are on carry-on devices that a user might bring into the vehicle.

However, VCS are not a panacea when it comes to distracted driving, and not all VCS are created equal. Though auditory-vocal interactions are the primary means of interacting with VCS, these systems as a whole are typically multi-modal as they usually include a visual element - often in the form of a display that is located on the centre console of the vehicle - and sometimes haptic elements, such as push to talk buttons. As a result, the effectiveness of these systems, including their ability to curb distraction and support safe driving, depends on the appropriate design of the individual elements as well the system as a whole. Inappropriate design of any of the components, such as a display that shows more information than is easy to parse at a glance or low voice recognition accuracy, can have undesirable effects. In a 2014 study, Reimer et al. (2014) found that despite attempts to streamline tasks by minimizing the number of required interactions per task, visual demand placed on drivers by VCS displays was still substantial. Another study showed that in some cases, VCS displays elicited "orienting responses" from drivers, i.e., drivers looked at or turned toward the display as if that is where the VCS were located (Reimer et al., 2013). Lo & Green (2013) found that low voice recognition accuracy i.e., inability of VCS to correctly recognize driver speech, resulted in variation in task completion times as the driver would need to repeat commands that the system did not understand. As highlighted by Czap & Pinter (2018), in-vehicle VCS voice recognition accuracy is impacted by several factors such as vehicle cabin noise, including media volume, conversations, etc., road noise, as well as capabilities of the “voice engine” itself. Several studies have explored the effects of different accuracy levels on driving performance. Kun et al. (2007) found that at accuracy levels of around 44%, there was greater steering angle variance. Gellatly & Dingus (1998) found that driving performance in the form of peak lateral and peak longitudinal acceleration was affected at accuracy levels below 60%.Other than being vulnerable to issues that arise from inappropriate design, VCS imposes more demands on the driver than baseline or “model” driving where the driver does not interact with any infotainment systems and solely focuses on the task of driving. However, given the pervasive nature of certain technologies in this era, and people’s expectations and habits surrounding technology use, it is unrealistic to expect that most drivers will engage in model driving when on the road. VCS might not be the perfect mitigator of driver distraction but, as mentioned earlier, because of their primary mode of interaction, these systems can have fewer negative impacts on road safety than using those that can only be operated via visual-manual interactions. Along with conducting research that continues to deepen our understanding of VCS’ strengths and weaknesses so that designs can improve in a way that enables safe driving, it is important to ascertain predictors of their use and adoption. After all, if these systems do not get used by drivers, their benefits do not get realized. The body of research on in-vehicle VCS has grown since these systems were first introduced with several studies investigating the effect of in-vehicle VCS on driving performance (Jenness et al., 2016; McCallum et al., 2004; McWilliams et al., 2015; Reimer et al., 2013, 2014; Strayer et al., 2017; Wu et al., 2015). However, there is limited data on how these systems are perceived and used. As mentioned above, a better understanding of how drivers use and perceive their in-vehicle VCS is needed to determine what factors foster their use. The objective of this thesis is to explore how drivers today use VCS and to identify factors that influence these usage patterns.

1.2 Research scope

The research focus of this thesis was revised in light of the COVID-19 pandemic. Originally, the main research interest of this thesis was whether system feedback could mitigate negative effects of background noise-dependent degradation in in-vehicle VCS accuracy on user perception of these systems and well as driving performance; Chapter 4 discusses this in more detail. To that effect, three studies had been planned: a focus group study and survey study to explore usage patterns and driver attitudes toward in-vehicle VCS, and a driving simulator study to examine the role of context as well as system reliability notifications on user perception of these systems. However, due to the COVID-19 outbreak, which was declared a pandemic by the World Health Organization on March 11, 2020, the University of Toronto halted all human subject research to comply with safety guidelines. As a result, the driving simulator study, which was underway at that time, had to be suspended. On account of the uncertainty around timelines for the safe resumption of studies involving human subjects, the scope and emphasis of this thesis was shifted to work with the data collected from the studies that had already been conducted, namely the focus group study and the survey study. As a result, objectives of this research were updated to explore current usage patterns of VCS, and to identify factors that impact adoption and use of VCS.

1.3 Thesis overview

- Chapter 2 introduces relevant literature, including assessment of acceptance of technology in related systems and domains
- Chapter 3 presents the two studies (focus group and survey) that were designed to explore current VCS usage patterns and the factors underlying said patterns
- Chapter 4 presents the work that has been done until date for the planned driving simulator study
- Chapter 5 provides a summary of the research contributions, limitations, and recommendations for future work.

Chapter 2

2.0 Literature Review

2.1 Acceptance of in-vehicle VCS

Knowledge about the factors that predict acceptance of in-vehicle VCS is limited, but some prior research has investigated this topic indirectly. For example, Kim & Lee (2016) conducted a survey study to examine the effects of user experience on user resistance to switching over to VCS in vehicles. They found that both switching cost, which was defined as "the perceived disutility a user would incur by switching from the status quo to a new situation" (Kim & Kankanhalli, 2009), and perceived value had an impact on user resistance. They go on to suggest that a user interface design which minimizes the time and effort required on the user's part to adapt to it is particularly important to mitigating user resistance. Another study by Lee, Mehler et al. (2015) which set out to investigate user perceptions toward in-vehicle smart technologies, including VCS, found that subjective perceptions of experience with a system was a stronger predictor of attitude toward that system than other measures, including task performance, preconceptions about that system, and user characteristics. The authors suggest that providers of novel in-vehicle technology should consider giving potential users opportunities to interact with these technologies prior to adoption as such exposure may build confidence and make positive impressions. An in-vehicle voice-calibration protocol is cited as an example of such an interaction; it would not only tune the system to the driver but also offer an opportunity for the driver to become acquainted with the style of interaction.

Besides positive initial interactions, prior experience with other voice technology has shown to have a positive impact on in-vehicle VCS acceptance. Kim & Lee (2016) found that people with significant prior experience with voice interfaces in other smart devices tended to have low user resistance toward changing over to using a voice interface in their vehicle. They attribute this behaviour to the extension of the lock-in effect (David, 1985) which states that users are likely to continue using a type of interface once they have become accustomed to it, even on dissimilar devices.

Previous research also suggests that VCS accuracy is an important predictor of acceptance. According to Jenness et al. (2016), a high error rate could lead drivers to visually verify commands and revert to visual-manual interaction. In a driving simulator study that compared two VCS with different levels of accuracy, in the presence of noise, Sokol et al. (2017) found that participants showed greater acceptance for the system that was more accurate.

2.2 Acceptance of voice technology

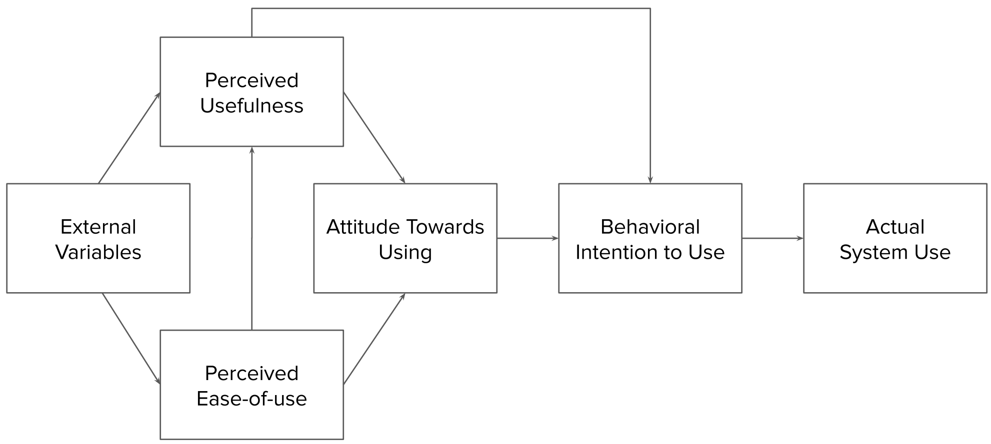
Given the limited knowledge about acceptance of in-vehicle VCS, it is valuable to review literature about acceptance and use of related technology. Voice assistants (VA), i.e., voice interfaces in non-vehicular contexts, is one such technology that has been explored in more depth. Though VAs are used in different environments and contexts, factors that predict the adoption and use of these systems may influence the adoption and use of in-vehicle VCS as well since auditory-vocal interactions are the primary mode of interactions for both system types. A study by Koon et al. (2020) examined VA use by people aged 55 and over and found that multiple factors including performance expectancy and effort expectancy served as facilitators, and in some cases barriers, to continued use. In a survey study, Liao et al. (2019) found that concerns around data privacy and security influenced one's likelihood to adopt a VA. The concern about privacy and its effect on VA adoption was also highlighted by Mclean & Osei-frimpong (2019), who found that perceived privacy risk, i.e., concerns about theft of personal or financial details as well as the VA listening in on private conversations, had a dampening effect on the perceived benefits of using such technology. Coskun-Setirek & Mardikyan (2017) found that output quality, i.e., accuracy of the system's responses, was a predictor of perceived usefulness of VA, which in turn predicted behavioural intention to use VA.

2.3 Modeling acceptance

2.3.1 Technology Acceptance Model

Various frameworks have been used in the research areas discussed above to explain acceptance of technology. Among them, several studies have used the Technology Acceptance Model or TAM. TAM was developed by Davis et al. (Davis, 1989) and has been used to explain usage and adoption of technology by many studies across multiple domains (Marangunić & Granić, 2015; Mortenson & Vidgen, 2016; Turner et al., 2010). According to this framework, perceived usefulness and perceived ease-of-use of a technology inform attitude toward using it, which in turn predicts behavioural intention to use that technology and actual usage. In other words, TAM posits that users are more likely to adopt systems that they believe have utility for them (usefulness) and offer a good user experience (ease-of-use). The framework also suggests that external variables such as individual differences, social conditions, etc., can mediate perceived usefulness and perceived ease-of-use. TAM's factors and relationships are illustrated in Figure 1.

Figure 1. Technology Acceptance Model (TAM) (Davis et al., 1989)



Over the years, TAM has received several criticisms. Bagozzi (2007) has claimed that it is unreasonable to expect a single simplistic model to "explain decisions and behavior fully across a wide range of technologies, adoption situations, and differences in decision making and decision makers." In addition, TAM's use of self-reported data to measure system use has been pointed out as being problematic with the criticism subjective measures are unreliable for measuring actual system use (Legris et al., 2003; Yousafzai et al., 2007). Several frameworks have been proposed to extend, refine and redefine TAM including TAM2 (Venkatesh & Davis, 2000), TAM3 (Venkatesh & Bala, 2008), UTAUT (Venkatesh et al., 2003), however the original model remains widely used.

Despite these criticisms, previous research has confirmed that the Technology Acceptance Model (TAM) in particular, or an extension of TAM, is a good way to model acceptance of in-vehicle VCS, VA, and in-vehicle technology. In exploring user acceptance of automobile technology, Lee, Reimer, et al. (2015) used in-vehicle voice interfaces (both car-embedded and smartphone) as an example and found that TAM was an appropriate framework for assessing acceptance in this domain. Upon conducting a review of empirical studies on user acceptance of driver assistance systems, Isa et al. (2015) found TAM to be a useful theoretical model for predicting technology usage behaviours in this domain. However, they also found that existing TAM constructs are not always sufficient to explain user acceptance toward certain technologies and that as a result, the theoretical model might need to be extended by incorporating additional constructs. Rahman et al. (2018) developed and extended TAM to create the Unified Model of Driver Acceptance (UMDA) which identified attitude, perceived usefulness, endorsement, compatibility and affordability as the factors most likely to influence a driver's decision to purchase and use driver support systems.

2.3.2 Other models

The Unified Theory of Acceptance and Use of Technology (UTAUT) framework has also been utilized in prior research. Koon et al. (2020) utilized the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2) framework to explore perceptions of VA by early adopters above the age of 55. Osswald et al. (2012) proposed the Car Technology Acceptance Model (CTAM) with the aim to identifying major determinants for technology acceptance in the vehicular context. CTAM extended the original Unified Theory of Acceptance and Use of Technology (UTAUT) framework to include anxiety and perceived safety. In Liao et al's (2019) survey study to explore motivations and barriers to adopting of VA among both users and non-users of this technology, various aspects of TAM and UTAUT frameworks was seen in respondents' decisions to adopt or reject these systems.

2.4 Research gaps

The literature reviewed in this chapter calls attention to the lack of knowledge about factors that influence in-vehicle VCS adoption. As mentioned in the introduction, these systems have the potential to increase driving safety, if designed appropriately; and appropriate design requires in-depth understanding of all the factors that encourage and discourage use of voice interfaces in the driving environment. To address these gaps, a qualitative analysis was conducted on data collected from a focus group study to explore how current drivers' user in-vehicle VCS with the aim of identifying factors that influence adoption. This was followed by a quantitative analysis of data collected via a survey study with the aim of illustrating how factors that impact in-vehicle VCS adoption relate to each other.

Chapter 3

3.0 Exploring VCS Usage Patterns: Focus Group and Survey

3.1 Focus group study

A focus group study with a total of 9 participants was conducted to explore how drivers use current in-vehicle VCS and what factors motivate these usage patterns. Given the limited knowledge about in-vehicle VCS acceptance, it was important to conduct exploratory research prior to carrying out a large-scale quantitative study. This focus group study acted as a heuristic device (Billson, 1989) which allowed for an in-depth exploration of subjective experiences pertaining to voice interfaces in the vehicle. The findings of this study were then used to formulate questions for and design the online survey study.

In an attempt to balance recommendations made by Krueger et al. (Krueger & Bank, 2001) for designing and conducting focus groups, including appropriate sample size, as well as practical considerations such as time and cost, this study was carried out via two sessions: the first session interviewed frequent users of this technology (N = 5) while the second session interviewed infrequent users (N = 4). By conducting two distinct sessions, this study was able explore the experiences of both high and low adoption users in enough detail without concerns around splitting the time and user representation. It also allowed the facilitator to ask questions that were relevant to most participants in each session, as opposed to about only half the participants.

This study was approved by University of Toronto’s Office of Research Ethics in April 2018 (REB Human Protocol Number 35870).

3.1.1 Participants

Participants were recruited through flyers and online classified ads. They were required to be 20 to 55 years of age, fluent in English, and had to have used in-vehicle VCS within the past three years. Individuals who indicated that they used in-vehicle VCS at a frequency higher than or similar to their driving frequency, e.g. used in-vehicle VCS a few times a day or a few times a week and drove a few times a week, were placed in the recruitment pool for frequent users group. On the other hand, individuals who indicated that they used in-vehicle VCS less frequently compared to how often they drove or that they had used these systems a few times and then stopped using them, were put in the pool for the infrequent users group.

Six people were recruited for each focus group, however, there was 1 no-show in the first session and 2 no-shows in the second session. Session 1 (S1) was held with frequent users and had a final count of 5 participants (2 females and 3 males), aged 31 – 44 (*M* = 37.6, *SD* = 5.64). Session 2 (S2), which interviewed infrequent users, had a final count of 4 participants (1 female and 3 males), aged 32 – 54 (*M* = 40.25, *SD* = 10.21). More details about these participants can be found in Table 1.

Participants were compensated at a rate of 14 CAD/hour and were provided with water, coffee, and snacks during both sessions.

Table 1. Profile of Focus Group Study Participants

Characteristic	N (%)	
	Session 1 (frequent users)	Session 2 (infrequent users)
Gender		
Female	2 (40)	1 (25)
Male	3 (60)	3 (75)
Age		
31-35	3 (60)	2 (50)
41-45	2 (40)	1 (25)
51-55		1 (25)
Most frequently used VCS type		
Connected	4 (80)	2 (50)
Embedded	1 (20)	2 (50)

3.1.2 Method

Both sessions of the focus group study were held on Saturday morning, about 5 weeks apart, and lasted between 2 and 2.5 hours, including short breaks. Upon arrival, each participant signed and read the consent form and then proceeded to fill out a pre-focus group questionnaire (Appendix D) that gathered data about driving behaviours, the vehicle they drove most frequently, the VCS they used most, and demographics. In both sessions, the facilitator (the author of this thesis) conducted the interviews and guided the participants through a slide deck (Appendix E), while two additional members of the research team took notes. Audio recordings were made using an Olympus WS-500M voice recorder.

Each session opened with a brief presentation about in-vehicle VCS to establish a common understanding of these systems, their functionality, the various types of systems i.e., connected (like Android Auto, Apple Car Play, or a smartphone, etc.) vs. embedded (like Ford Sync, Tesla IVI, BMW iDrive, etc.), and the terminology that would be used in the session. The following pre-determined, open-ended questions introduced topics of interest to the participants:

1. What tasks do you use in-vehicle VCS for?
2. What tasks do you avoid using in-vehicle VCS for?
3. When do you use in-vehicle VCS?
4. When do you avoid using in-vehicle VCS?
5. What do in-vehicle VCS do well?
6. Where do in-vehicle VCS fall short?
7. How does the accuracy of in-vehicle VCS affect your usage?
8. Has anything within the environment of the vehicle affected your use of in-vehicle VCS systems? *(Facilitator prompted about background noise if that topic did not emerge naturally)*
9. What if the in-vehicle VCS notified you when it experienced a drop in accuracy?

Based on participant responses, follow-up questions were asked to gather further details.

3.1.3 Analysis and results

A general inductive analysis methodology was used to analyze the data collected in the focus group sessions. This method is recommended for “research findings to emerge from the frequent, dominant, or significant themes inherent in raw data, without the restraints imposed by structured methodologies” (Thomas, 2006, p. 238). As the focus group study was designed to explore the relatively under-researched topic of in-vehicle VCS usage patterns, a general inductive analysis was deemed appropriate.

On the Monday following each session (which were held on Saturdays), the following procedure, as suggested by Thomas (2006) , was used for inductive analysis of the qualitative data:

1. Data cleaning: Audio recordings, notes, and questionnaire responses were consolidated, processed, and prepared for review
2. Close reading: Cleaned data was reviewed by the author of the thesis with assistance from the facilitators of the focus group sessions
3. Category creation: Recurring responses were noted as themes; consensus as well as disparity between participant responses were noted
4. Overlapping coding and uncoded text
5. Reduction and finalization of themes

3.1.3.1 Tasks and situations

Navigation, entertainment (music, radio, and podcasts) and communication (calling and texting) were the most common tasks that in-vehicle VCS were used for. Two participants stated that they used VCS for climate control and retrieving live traffic information. Participants avoided using VCS to engage in tasks that they considered to be particularly visually or cognitively demanding, including playing games and watching videos, as they thought these would negatively impact their driving. One participant said that they avoided tasks that might negatively impact their emotional state, such as checking messages and email.

Participants reported using in-vehicle VCS particularly when they drove in unfamiliar areas, were lost, were running-late or driving on the highway. Two participants also mentioned using these systems when they felt bored (usually while being stuck in traffic) or when they felt tired and/or drowsy. Two participants mentioned avoiding VCS when they found themselves in demanding driving situations so that they could focus solely on the driving task.

3.1.3.2 Performance and functionality

Participants said that they appreciated the hands-free aspect of VCS which according to them was less distracting than manual interactions. They also reported that voice interactions worked well for certain tasks such as navigation, communication and entertainment search and selection. On the other hand, participants thought that voice recognition was often erroneous and that there were limitations in functionality. One S1 participant said they would like the ability to check the status of their vehicle (e.g., if an oil change was needed) via VCS commands. A participant from S2 said that they would like voice notifications about roadway objects in their blind spot.

3.1.3.3 Accuracy and background noise

Participants reported that voice recognition accuracy was better for some tasks than others. There was also consensus about in-vehicle VCS generally having more trouble recognizing addresses and names than other commands. When asked about background noise, participants stated that its presence in the form of people talking, construction sounds, and sirens interfered with in-vehicle VCS interactions. Two participants said that they would avoid using VCS altogether at times when the recognition accuracy was low.

3.1.3.4 VCS feedback

6 participants reported that feedback from the VCS would be helpful if it were accurate and presented appropriately. One S1 participant said that notifications about low accuracy might prevent them from "wasting time" as they would not use VCS when it was having trouble understanding her.

3.1.3.5 Privacy

Participants had privacy concerns about in-vehicle VCS "always listening" to them and were unsure about whether their data was being stored safely by the VCS provider. Two participants said that they preferred using the push-to-talk button (usually located close to the steering wheel) than use activation or trigger phrases to begin interactions with the in-vehicle VCS. This concern about privacy extended to the presence of others in the vehicle with 3 participants stating that they avoided using VCS in the presence of passengers.

3.1.3.6 Attitude toward technology

In the themes mentioned above, the responses between the two groups had not differed in any discernable way. When it came to attitude toward technology in general, however, responses from S1 and S2 diverged.

The frequent users had a more forgiving attitude toward technology and were more tolerant of errors. For example, a participant from S1 said they thought bugs in new technology was to be expected and that these systems were expected to improve over time. In contrast, participants from the infrequent group had a demanding attitude toward technology and were less tolerant about glitches. One S2 participant said that “first impressions” determined whether they would continue to use a system or not, regardless of how new the technology was.

3.1.4 Summary

The focus group study did not find notable differences in the usage patterns (in the form of commands that they used, the situations that they used VCS in, etc.) of drivers that used in-vehicle VCS frequently and those that did not. Both groups expressed some concerns around privacy for these devices though this did not actually prevent them from using them. Participants also reported frustration in the event of low system accuracy, with some reporting discontinuation of use.

The main difference between the two groups was their attitude toward technology in general, not just toward the in-vehicle VCS: frequent users were more tolerant toward errors and inconsistency in a system’s performance, especially when it came to novel technology, whereas infrequent users had a significantly lower threshold for errors, irrespective of the maturity of the technology.

3.2 Survey

A survey study was conducted to examine in-vehicle VCS usage in more depth with a larger sample of participants. TAM constructs of perceived usefulness of VCS, perceived ease-of-use of VCS, attitude toward VCS, and actual VCS use were described using the data collected.

Further, two additional constructs, attitude toward technology and use of VA (i.e., voice control technology in non-driving contexts such as Google Assistant, Siri, Alexa, Bixby, etc.), were built from the survey data. Attitude toward technology was included based on the findings of the focus group study (Section 3.1.3) whereas the VA use was identified as a predictor of in-vehicle VCS use by prior literature (Chapter 2). Further, perceived accuracy of in-vehicle VCS, which was highlighted as an important factor in both the focus group study findings and reviewed literature, was used to describe attitude toward VCS.

It was hypothesized that:

1) Perceived usefulness of VCS and perceived ease-of-use of VCS would significantly predict attitude toward VCS, as outlined by TAM

2) Both attitude toward technology and use of VA would predict attitude toward VCS but to a lesser extent than the TAM constructs in 2)

The proposal for this study was originally approved by University of Toronto's Office of Research Ethics in May 2019 and renewed in May 2020 for another year (REB Human Protocol Number 37614).

3.2.1 Participants

To be eligible, respondents were required to be drivers that used in-vehicle VCS technology, 20-55 years old, and current residents of the United States of America or Canada. On average, participants took 19 minutes to complete the survey and were not permitted to skip any questions. Respondents were compensated 4 USD on completion of the survey.

A total of 219 respondents completed the survey from June 2019 to August 2019. Twenty-one respondents were removed during data processing and not included in the analyses:

- Twelve respondents were removed because they chose the response "I don't use one" to Q13: "What kind of voice command system (VCS) do you use most often while driving?"
- Five respondents were removed because they chose the response "None" to Q7: "Approximately how many years have you been driving with at least a learner's license?"

- Four respondents were removed for not meeting minimum criteria; one participant, for having chosen the response “A few times a year”, and another participant for having chosen “A few times a month” to Q8: “How often do you drive?” and two participants, for choosing “I have no opinion” to Q15: “Which of these statements best reflects how you feel about the VCS technology in the car you drive? (Select the closest answer.)”

Two participants reported their age as 56 which was above the cut-off for recruitment. However, they were not removed from analysis. The final sample size was 198; a profile of the respondents can be found in Table 2.

Table 2. Profile of Survey Study Participants

Characteristic	N (%)
Gender	
Female	100 (50.5)
Male	98 (49.5)
Age	
20-24	6 (3)
25-29	33 (16.7)
30-34	52 (26.3)
35-39	40 (20.2)
40-44	32 (16.2)
45-49	20 (10.1)
50-54	9 (4.5)
55-56	6 (3)
Driving Experience	
1-5 years	5 (2.5)
5-10 years	20 (10.1)
10-15 years	46 (23.2)
15 years	127 (64.1)
Driving Frequency	
Every day	162 (81.8)
A few times a week	36 (18.2)
Most frequently used VCS type	
Connected	31 (15.7)
Embedded	41 (20.7)
Smartphone	126 (63.6)

3.2.2 Method

The survey was designed to collect data about participants' in-vehicle VCS usage, VA usage, attitudes toward technology, as well as driving habits and behaviours. Most survey questions were drawn directly or adapted from existing literature as they were recognized as reliable and valid instruments for measures of interest. These sources included questionnaires to assess effects of in-vehicle VCS on driver behaviour (Reimer et al., 2013), previous surveys that explored consumer interest in automation (Abraham et al., 2017) as well as trust around autonomous vehicles (Abraham et al., 2016), trust between people and automation (Jian et al., 2000), the Voice Control Tasks Experience Questionnaire (Jenness et al., 2016), the Media and Technology Usage and Attitudes Scale (Rosen et al., 2013), a previous survey about attitudes toward privacy and security (Madden & Rainie, 2015), and the Manchester Driving Behaviour Questionnaire (Reason et al., 1990). To delve into a few specific topics that had little coverage in prior research, but were deemed important and relevant for this study, some questions authored by the research team were also included in the questionnaire. Table 3 lists the survey questions, their sources and the constructs they represented.

Questions were presented in a pre-determined order, i.e., there was no randomization, and were broken down into the following distinct sections: general demographics, (usage of and opinions about) in-vehicle voice command system, (usage of and opinions about) voice assistants, and usage of and opinions about technology at large. The final questionnaire (Appendix F) comprised of 47 questions, all of which were required, i.e., no questions could be skipped. The survey was hosted online using SurveyGizmo and Amazon Mechanical Turk was used to recruit and compensate participants.

At the time that the survey was conducted, it was being treated as an exploratory study, auxiliary to the planned driving simulator study. A sample size that would allow for the possibility of carrying out different analyses including SEM was desirable. However, determining sample for SEM is not straightforward. Though there is consensus in academic community about this analysis requiring "large" sample size, there is no single universally-accepted way to calculate appropriate sample size. Among some of the more commonly used guides and rules of thumb for SEM sample size is Comrey & Lee (2013)'s recommendation of 300 and Nunnally's (1994) recommendation that there be 10 cases per variable. As per Nunnally's recommendation, 290 would have been an appropriate sample size given the variables that constituted the constructs of interest (Table 4). Based on the above, sample size of 250-300 was deemed appropriate.

Table 3. Sources of survey questions

Source	Questions
Demographics questions used by the Human Factors and Applied Statistics lab	Consent: Q1 General Demographics: Q2 (age), Q3 (sex), Q4 (state/province), Q5 (city), Q6 (driver's license), Q7 (driving experience in years), Q8 (driving frequency), Q9 (weekly driving distance), Q10 (most-driven vehicle type), Q11 (vehicle information), Q12 (reasons for driving)
The Effects of a Production Level "Voice-Command" Interface on Driver Behavior: Reported Workload, Physiology, Visual Attention, and Driving Performance (Reimer et al., 2013)	In-vehicle voice control systems: Q16 (VCS accuracy),
Autonomous Vehicles, Trust, and Driving Alternatives: A survey of consumer preferences (Abraham et al., 2016)	General Demographics: Q11 (vehicle information) In-vehicle voice control systems: Q27 (trust in automaker for VCS), Q28 (trust in tech company for VCS) Voice assistants: Q41 (trust in tech company for VA)
Consumer Interest in Automation: Preliminary Observations Exploring a Year's Change (Abraham et al., 2017)	In-vehicle voice control systems: Q15 (happiness with VCS), Q17 (learning of VCS), Q18 (preferred learning of VCS) Voice assistants: Q42 (learning VA), Q43 (preferred learning VA)
In-Vehicle Voice Control Interface Performance Evaluation (Jenness et al., 2016)	In-vehicle voice control systems: Q19 (VCS commands), Q21 (ideal VCS commands) Voice assistants: Q36 (VA commands), Q38 (ideal VA commands)
Initial Scale Items for Perceived Usefulness (Davis, 1989)	In-vehicle voice control systems: Q25 (VCS usefulness) Voice assistants: Q39 (VA usefulness)
Initial Scale Items for Perceived Ease of Use (Davis, 1989)	In-vehicle voice control systems: Q26 a-g (VCS ease-of-use) Voice assistants: Q40 a-g (VA ease-of-use)
Checklist for Trust between People and Automation (Jian et al., 2000)	In-vehicle voice control systems: Q26 h-l (VCS ease-of-use) Voice assistants: Q40 h-l (VA ease-of-use)
Media and Technology Usage and Attitudes Scale (Rosen et al., 2013)	General Technology: Q44 (technology use frequency), Q45 (attitude toward technology),

Americans’ Attitudes About Privacy, Security and Surveillance (Madden & Rainie, 2015)	Privacy & Security: Q46 (importance of privacy) and Q47 (perceived control over privacy)
Manchester Driving Behaviour Questionnaire (Reason et al., 1990)	Driving: Q48 (driving behaviours)
Composed by the author of this thesis	In-vehicle voice control systems: Q13 (VCS type), Q14 (VCS use frequency), Q20 (Other VCS commands), Q22 (VCS use situations), Q23 (VCS improvements for functionality and accuracy), Q24 (other VCS improvements needed) Voice assistants: Q29 (use VA or not), Q30 (reasons for not using VA), Q31 (VA use frequency), Q32 (VA type), Q33 (VA accuracy), Q34 (reasons for using VA), Q35 (VA use situations), Q37 (other VA commands)

3.2.3 Analysis and results

All statistical analysis of the data was performed using RStudio 1.3.959 running R 4.0.0. Two visualizations were created using Excel for Microsoft 365.

First, relevant questions from the survey were mapped to constructs of interest borrowed from TAM (VCS perceived usefulness, VCS perceived ease-of-use, attitude toward VCS, and actual VCS use) as well as constructs representing factors that were identified as important in the focus group study, namely attitude toward technology and voice assistant use; Table 4 shows the breakdown of constructs by item. These items were initially hand-selected based on the combination of the phrasing and the response scale, after which they were checked for inter-item reliability[1]. The measurement models that were built (Section 3.2.2.2.1) showed that these constructs were also unidimensional. Next, descriptive statistics were calculated for these constructs (Table 5), following which structural equation models (SEM) were built to examine the relationships between them. Descriptive statistics were also calculated for self-reported frequency of in-vehicle VCS tasks and self-reported frequency of in-vehicle VCS use in different situations (Figures 3 and 4). These variables were not considered for model testing via SEM but still describe important aspects of in-vehicle VCS usage. Finally, a multiple linear regression was built to further examine the relationships between the constructs.

Table 4. Constructs and their corresponding survey items

VCS Perceived Usefulness (vcsPU) *1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly disagree*	
Q25. Please rate the degree to which you agree or disagree with the following statements: Using in-vehicle VCS…	
a	while driving enables me to accomplish tasks more quickly as compared to visual/manual interactions with systems within the vehicle.
b	improves my driving performance as compared to visual/manual interactions with systems within the vehicle.
c	while driving increases my productivity as compared to visual/manual interactions with systems within the vehicle.
d	makes it easier to drive as compared to visual/manual interactions with systems within the vehicle.

[1] Principal component analysis and confirmatory factor analysis were used to build and assess the constructs of interest; these results are not reported in this thesis.

VCS Perceived Ease-of-use (vcsPEU) *1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly disagree*	
Q26. Please rate the degree to which you agree or disagree with the following statements:	
a	Learning to operate in-vehicle VCS is easy for me.
b	Interacting with in-vehicle VCS requires a lot of mental effort.
c	I find it easy to get in-vehicle VCS to do what I want to do.
e	I find in-vehicle VCS to be flexible to interact with.
f	I find it takes almost no effort to become skillful at using in-vehicle VCS.
g	Overall, I find in-vehicle VCS easy to use.
Positive Attitudes Toward Technology (techAttPos) *1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly disagree*	
Q 45. Please rate the degree to which you agree or disagree with the following statements:	
a	I feel it is important to be able to find any information whenever I want online
b	I feel it is important to be able to access the Internet any time I want.
c	I think it is important to keep up with the latest trends in technology.
g	Technology will provide solutions to many of our problems.
h	With technology, anything is possible.
i	I feel that I get more accomplished because of technology.
Anxiety About Being Without Technology or Dependence on Technology (techAttAnx) *1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly disagree*	
Q 45. Please rate the degree to which you agree or disagree with the following statements:	
d	I get anxious when I don't have my cell phone.
e	I get anxious when I don't have the Internet available to me.
f	I am dependent on my technology.
Negative Attitudes Toward Technology (techAttNeg) *1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly disagree*	
Q 45. Please rate the degree to which you agree or disagree with the following statements:	
j	New technology makes people waste too much time.
k	New technology makes life more complicated
l	New technology makes people more isolated.
Attitude toward in-vehicle VCS (vcsAtt)	
Q31. How often do you use VA? *1 = Never, 2= At least once a year, 3 = At least once a month, 4 = At least once a week, 5 = At least once a day*	
Attitude toward in-vehicle VCS (vcsAtt)	
Q26. Please rate the degree to which you agree or disagree with the following statements: *(1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly disagree)*	
i	In-vehicle VCS is dependable.
k	In-vehicle VCS is reliable.
l	I can trust in-vehicle VCS.

Q15. Which of these statements best reflects how you feel about the VCS technology in the car you drive? (Select the closest answer.) *1 = I'm very unhappy with the VCS technology, 2 = I like a few of the VCS features, 3 = I like most of the VCS features, 4 = I'm very happy with the VCS technology, 5 = I have no opinion*
Q16. Do you think your VCS is accurate? *(10-point Likert scale: 1 = Very inaccurate, 10 = Very accurate)*
Actual in-vehicle VCS Use (vcsUse)
Q14. How often do you use your in-vehicle VCS while driving? *1 = Never, 2 = Rarely (i.e. I don't use it very often when I drive), 3 = Occasionally (i.e. I use it every few times I drive), 4 = Often (i.e. I use it almost every time I drive), 5 = Always (i.e. I use it every time I drive)*

3.2.3.1 Descriptive statistics

When asked about tasks that they used in-vehicle voice commands for (Question 19 or Q19 in survey; Figure 3), participants reported asking for directions, asking for the weather, checking traffic alerts, finding local businesses, calling a contact, and playing audio with high frequency. On the other hand, they reported lower frequencies for checking news headlines, doing calculations, looking up movie times or sport scores, managing or looking up calendar events, looking up measurements, finding recipes, managing alarms, and controlling other smart devices. Figure 3 shows participant responses for this question.

Participants reported using in-vehicle VCS (Q22; Figure 4) more frequently when driving in bad traffic, driving at low speeds, parked or when in an unfamiliar place. They reported using these systems less frequently when driving in bad weather, where others were present in the vehicle, or when mentally fatigued. Lowest usage frequency was reported for situations where participants drove at high speeds. Figure 4 illustrates the reported usage of in-vehicle VCS in various driving situations.

Figure 2. Participants' reported usage of in-vehicle VCS for different tasks (Q19)

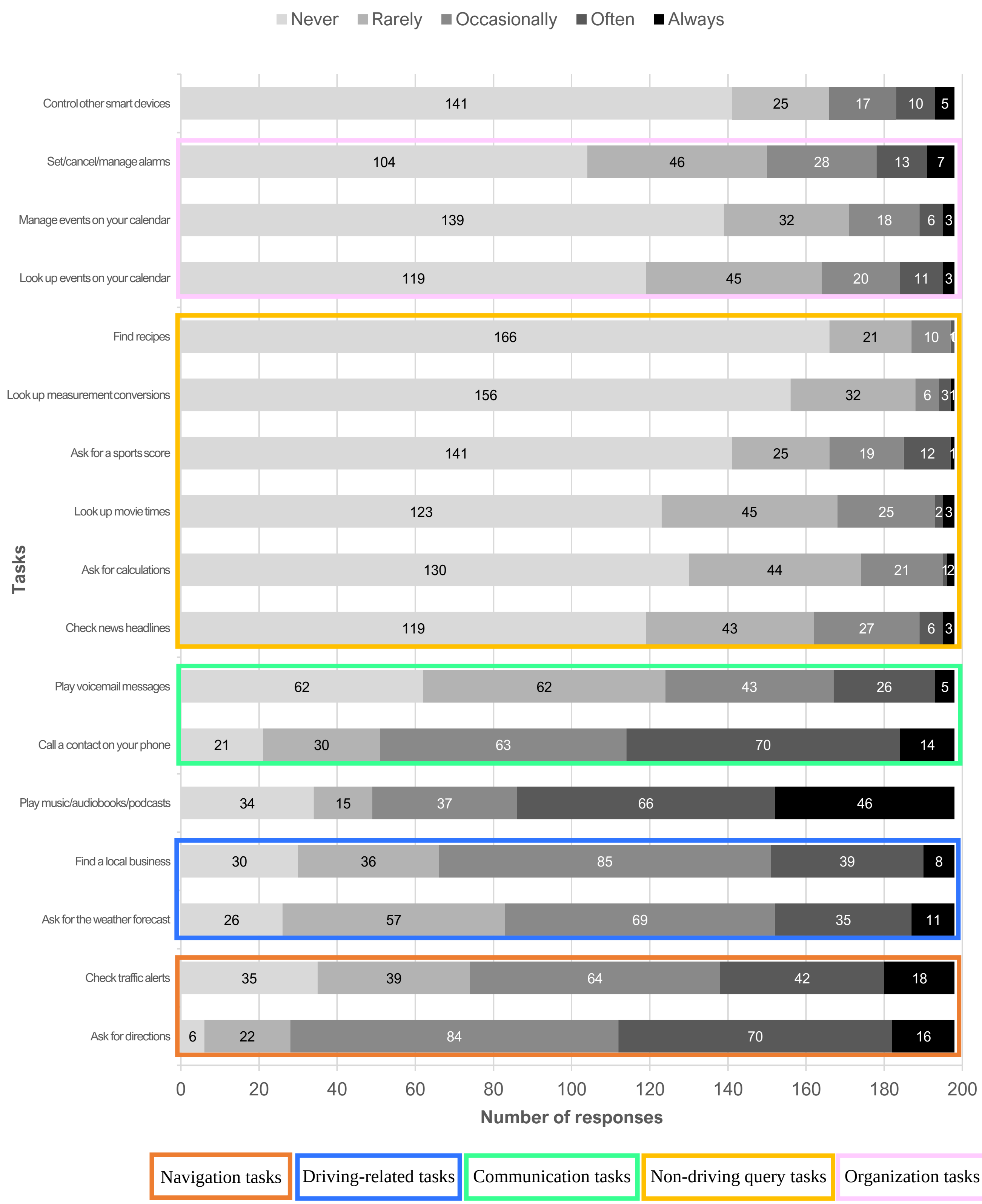
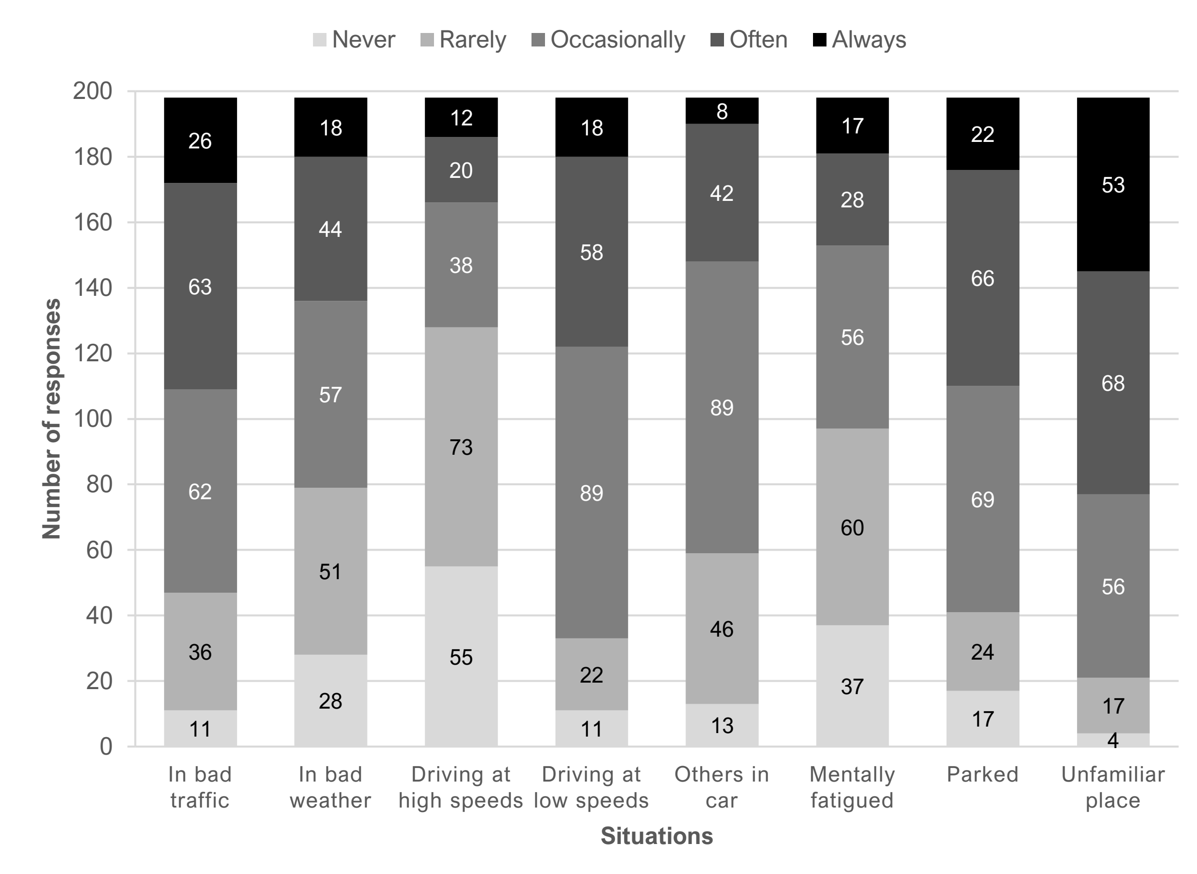


Figure 3. Participants' reported in-vehicle VCS use in different driving situations (Q22)



On average, participants reported to find in-vehicle VCS useful for driving (Q25b, Q25d) as well as accomplishing tasks while driving (Q25a, Q25c). They also reported that these systems were easy to use (Q26a, Q26c, Q26e, Q26f, Q26g) and did not require much mental effort (Q26b). When it came to attitude toward technology, participants reported feeling generally positive about technology (Q45a-c and Q45g-i) but they also expressed some anxiety in this area (Q45d-f). Negative attitudes toward technology has lower average scores, except for 45l (mean = 3.2) which asked whether participants believed that new technology made people more isolated. More participants also reported to using VA (Q31, N = 173) than not (N = 25). Table 5 shows more detailed descriptive statistics for these measures.

Table 5. Model constructs: descriptive statistics and results of SEM measurement model

Constructs and Questions	Descriptive Statistics			Standard factor loadings (all p <.0001)				Cronbach's α
				Measurement Model A		Measurement Model B		
	Median	Mean	SD	Coeff.	SE	Coeff.	SE	
VCS Perceived Usefulness (vcsPU)								0.78
*1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly disagree; denoted by * in rest of table*								
Q25a *	4	3.95	0.83	0.718		0.715		
Q25b *	4	3.75	0.99	0.647	0.136	0.662	0.141	
Q25c *	4	3.69	0.9	0.661	0.124	0.640	0.128	
Q25d *	4	3.96	0.89	0.716	0.124	0.705	0.129	
VCS Perceived Ease-of-use (vcsPEU)								
Q26a *	4	4.24	0.75	0.724		0.716		
Q26b *	2	0.98	0.98	-0.565	0.132	-0.559	0.141	
Q26c *	4	4.09	0.8	0.789	0.108	0.784	0.115	
Q26e *	4	3.76	0.93	0.636	0.126	0.639	0.133	
Q26f *	4	3.87	1.05	0.755	0.141	0.756	0.149	
Q26g *	4	4.22	0.77	0.840	0.103	0.829	0.111	
Positive Attitudes Toward Technology (techAttPos)								0.8
Q45a *	5	4.47	0.65			0.624		
Q45b *	5	4.46	0.72			0.609	0.161	
Q45c *	4	4.01	0.9			0.720	0.208	
Q45g *	4	4.15	0.78			0.658	0.175	
Q45h *	4	3.92	0.98			0.592	0.215	
Q45i *	4	4.26	0.76			0.631	0.171	
Anxiety About Being Without Technology or Dependence on Technology (techAttAnx)								0.84
Q45d *	4	3.38	1.24			0.753		
Q45e *	4	3.57	1.16			0.885	0.100	
Q45f *	4	3.84	1.02			0.767	0.081	
Negative Attitudes Toward Technology (techAttNeg)								0.8
Q45j *	3	2.83	1.26			0.864		
Q45k *	2	2.58	1.27			0.760	0.093	
Q45l *	3	3.2	1.27			0.651	0.089	
Voice Assistant Use (vaUse)								-
1 = Never, 2= At least once a year, 3 = At least once a month, 4 = At least once a week, 5 = At least once a day								
Q31	4	3.83	1.37					

Attitude toward in-vehicle VCS (vcsAtt)								0.82
1 = I'm very unhappy with the VCS technology, 2 = I like a few of the VCS features, 3 = I like most of the VCS features, 4 = I'm very happy with the VCS technology, 5 = I have no opinion								
Q15	3	3.12	0.76	0.600		0.610		
Likert scale: 1 = Very inaccurate, 10 = Very accurate								
Q16	8	8.01	1.57	0.623	0.292	0.614	0.288	
Q26i *	4	4.03	0.73	0.872	0.151	0.877	0.148	
Q26k *	4	4.02	0.74	0.882	0.154	0.878	0.149	
Q26l *	4	3.92	0.78	0.772	0.153	0.769	0.149	
Actual in-vehicle VCS Use (vcsUse)								-
1 = Never, 2 = Rarely, 3 = Occasionally, 4 = Often, 5 = Always								
Q14	3	3.4	0.89					

Participants claimed to like most features of their in-vehicle VCS (Q15) and reported a high perceived accuracy for the in-vehicle VCS they used (Q16). They also self-reported finding these systems dependable (Q26i), reliable (Q26k), and that they could trust in-vehicle VCS (Q26l). Generally, participants of this survey reported high frequency of usage for these systems (Q14). When asked how often they used their in-vehicle VCS while driving, 27 (18.6%) chose “Rarely (i.e. I don't use it very often when I drive)”, 92 (46.5%) selected “Occasionally (i.e. I use it every few times I drive)”, 52 (26.3%) selected “Often (i.e. I use it almost every time I drive)”, and 27 (18.6%) individuals chose “Always (i.e. I use it every time I drive)”.

3.2.3.2 Structural Equation Modeling

Four models were built to test different combinations of the latent variables constructed above as predictors of attitude toward VCS, and in turn, actual VCS use; this was done to compare the extent of influence of the two non-TAM constructs, attitude toward technology and use of voice assistants, individually and together, in combination with the TAM constructs of perceived usefulness and perceived ease-of-use. Section 3.2.2.2.2 covers these models in further detail.

Many different fit statistics exist to assess SEM. In this thesis, the following criteria were used: Chi-square divided by its degrees of freedom (χ^2/DF < 5), the Comparison Fit Index (CFI > 0.90), the Tucker-Lewis Fit Index (TLI > 0.90), the Root Mean-Square Error of Approximation (RMSEA < 0.08) and the Standardized Root Mean Square Residual (SRMR < 0.08) (Bentler, 1990). Though the chi-square to DF ratio (χ^2/DF) was reported for these models, they were given lower weight as previous research has indicated that this statistic can be overly sensitive to sample size (Bollen, 1989; Jöreskog, 1993).

3.2.3.2.1 Measurement Model

Two measurement models were constructed for structural models described in the section below. Measurement model A was built with VCS perceived usefulness (vcsPU), VCS perceived ease-of-use (vcsPEU), and attitude toward VCS (vcsAtt) modeled as first order latent variables. In measurement model B, subscales for attitude toward technology (techAttPos, techAttAnx, and techAttNeg)[2] were modeled as first order latent variables, along with the constructs included in model A. Use of VCS and use of VA were each represented by single variable in the SEMs and as a result were not included in either measurement model. Fit indices for measurement model A showed good fit with $\chi^2(87) = 197.074$, $p < .001$, $\chi^2/DF = 2.27$, CFI = 0.930, TLI = 0.916, RMSEA = 0.080 [90% Confidence Interval (CI): 0.065 – 0.095], SRMR = 0.054; fit indices for measurement model B also showed good fit showed good fit with $\chi^2(309) = 533.828$, $p < .001$, $\chi^2/DF = 1.73$, CFI = 0.907, TLI = 0.894, RMSEA = 0.062 [90% Confidence Interval (CI): 0.053 – 0.070], SRMR = 0.063. Table 4 shows detailed results of both measurement models.

3.2.3.2.2 Structural Models

As mentioned prior, four structural models were built to compare different combinations of factors for predicting attitude toward VCS. The first model (SEM1) depicted baseline TAM with only VCS perceived usefulness and VCS perceived ease-of-use as predictors of attitude toward VCS, the second model (SEM2) looked at VCS perceived usefulness, VCS perceived ease-of-use, and VA use as predictors of attitude toward VCS while the third model (SEM3) staged VCS perceived usefulness, VCS perceived ease-of-use, and the subscales of attitude toward technology as predictors of attitude toward VCS and the fourth model (SEM4) combined SEM2 and SEM3 to include both attitude toward technology and VA use as predictors of attitude toward VCS, along with the VCS perceived usefulness and VCS perceived ease-of-use. Table 6

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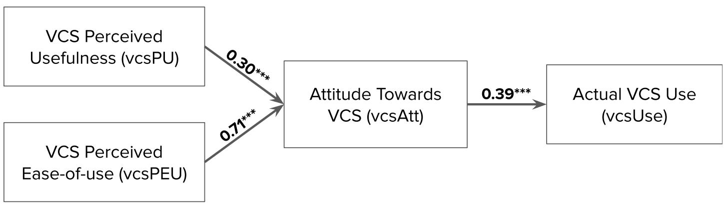
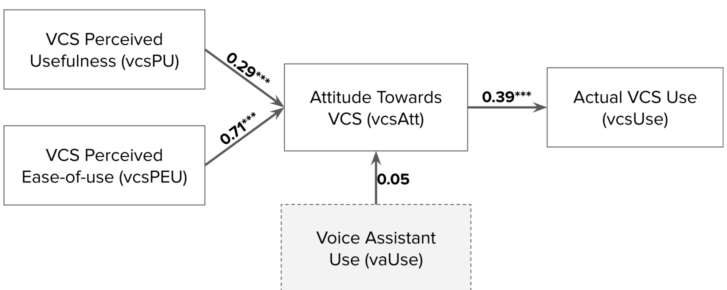
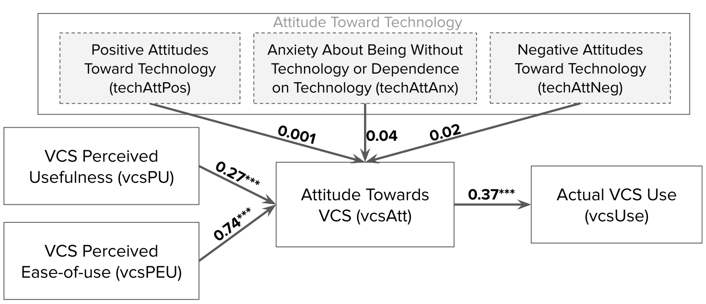
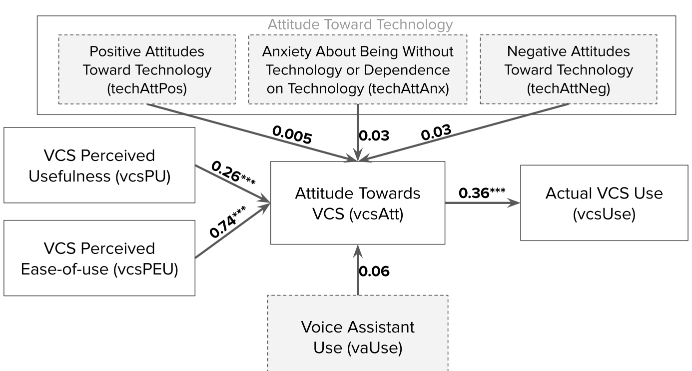
[2] The subscales for attitude toward technology were not combined into a second order latent variable based on the results of comparative confirmatory factor analysis and how the subscales were used in the source literature. These results are not reported in this thesis.

Table 6. Comparison of Structural Models (*** = p < .001.)

Structural Model	χ^2/df < 5	CFI > .9	TLI > .9	RMSEA < 0.08	SRMR <0.08
SEM1  	**2.30**	**.920**	**.905**	**0.080**	**0.057**
SEM2  	**2.28**	**.904**	.887	0.083	0.094
SEM3  	**1.77**	.895	.881	**0.064**	**0.064**
SEM4  	**1.83**	.880	.866	**0.066**	**0.079**

compares the fit of these models. Behavioral Intent was dropped as a factor from the base model as no questions in the survey represented this construct.

In all four models, results of regression shows that VCS perceived usefulness and VCS perceived ease-of-use were significant predictors of attitude toward VCS, which in turn was a significant predictor of use of VCS; Table 6 details the standardized path coefficients and their p-values while Table 7 shows estimated correlations. At the same time, none of the subscales for attitudes toward technology nor VA use were significant predictors of attitude toward VCS.

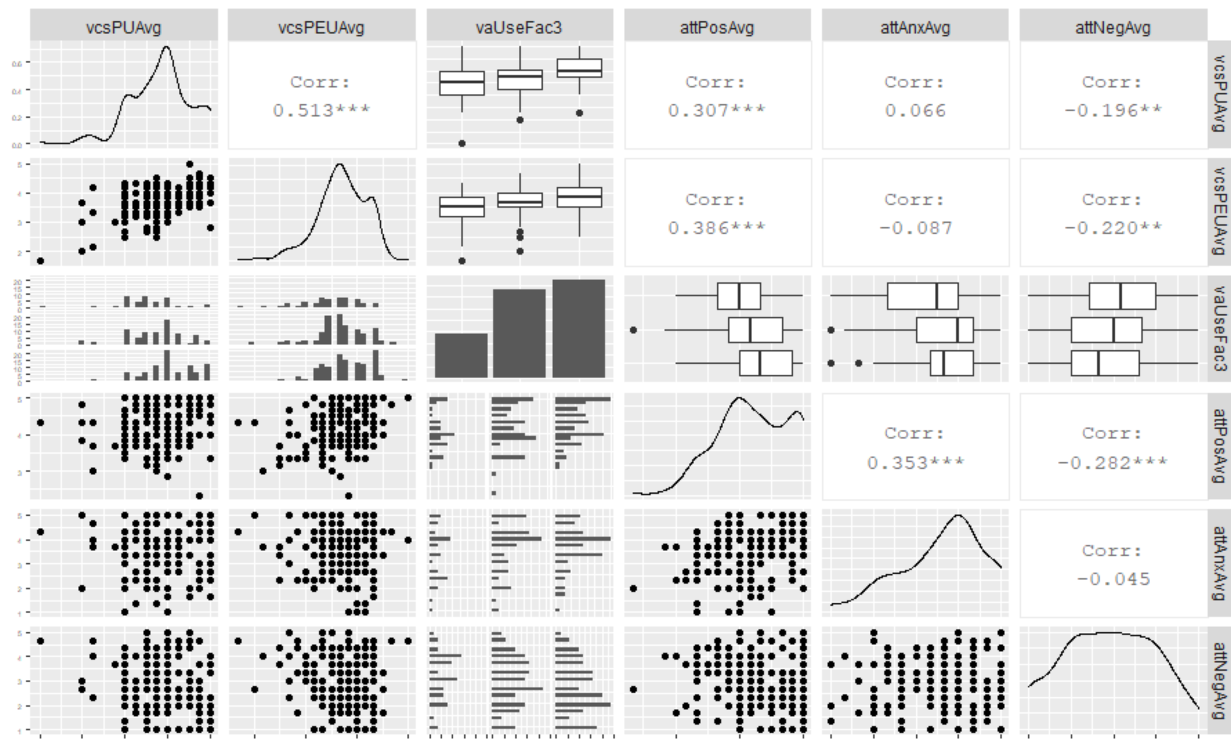
Table 7. Estimated correlations between latent predictors in the four SEMs

Model	vcsPU	vcsPEU	techAttPos	techAttAnx	techAttNeg
SEM1					
VCS Perceived Usefulness (vcsPU)	1				
VCS Perceived Ease-of-use (vcsPEU)	0.631	1			
SEM2					
VCS Perceived Usefulness (vcsPU)	1				
VCS Perceived Ease-of-use (vcsPEU)	0.632	1			
SEM3					
VCS Perceived Ease-of-use (vcsPEU)	1				
VCS Perceived Ease-of-use (vcsPEU)	0.628	1			
Positive Attitudes toward technology (techAttPos)	0.368	0.434	1		
Anxiety About Being Without Technology or Dependence on Technology (techAttAnx)	0.059	-0.124	0.419	1	
Negative Attitudes Toward Technology (techAttNeg)	-0.254	-0.293	-0.350	-0.072	1
SEM4					
VCS Perceived Ease-of-use (vcsPEU)	1				
VCS Perceived Ease-of-use (vcsPEU)	0.628	1			
Positive Attitudes toward technology (techAttPos)	0.368	0.434	1		
Anxiety About Being Without Technology or Dependence on Technology (techAttAnx)	0.059	-0.124	0.419	1	
Negative Attitudes Toward Technology (techAttNeg)	-0.254	-0.293	-0.350	-0.072	1

3.2.3.3 Multiple Linear Regression

Since the fit statistics of the SEM that used all four constructs of interest to describe attitude toward VCS (SEM4) were below thresholds that indicated good fit, a multiple linear regression model was built to further examine the relationships between them. To begin, composite scores were created for the constructs by averaging constituent items (Table 4). Figure 5 shows how these composite scores correlated with each other.

Figure 4. Correlation between composite scores for constructs



Composite scores for VCS perceived usefulness, VCS perceived ease-of-use, positive attitude toward technology, anxiety about technology, and negative attitude toward technology represent averages of 5-point Likert scale items and were treated as continuous in the analysis. Attitude toward VCS, which comprised of items with different scales, was also treated as a continuous variable in the analysis. In addition, VA use was included as categorical with three levels representing low, moderate and high users of voice assistant technology.

A linear model was constructed using attitude toward VCS score as the response variable and composite score for the six factors mentioned above as explanatory variables (Table 7). Level 1 of VA use was used as baseline.

Table 8. Linear Model

	Estimate	Std. Error	t-value	p-value	R^2 (Adjusted R^2)
Intercept	0.43	0.39	1.12	.26	.59 (.57)
VCS Perceived Usefulness	0.30	0.06	4.88	**2.23e-06**	
VCS Perceived Ease-of-use	0.72	0.09	8.16	**5.16e-14**	
VA Use (level 2)	0.14	0.10	1.37	.17	
VA Use (level 3)	0.17	0.10	1.67	**0.09**	
Positive attitudes toward technology	0.13	0.08	1.73	**0.09**	
Anxiety toward being without technology	-0.07	0.04	-1.70	**0.09**	
Negative attitudes toward technology	-0.02	0.03	-0.63	0.52	

3.2.4 Summary

Among the structural equation models, SEM1, which only contained TAM constructs, had the best fit. SEM2, which introduced VA use, showed worse fit with TLI (0.887), RMSEA (0.083), and SRMR (0.094) values that were above and below the required thresholds. In SEM3, attitude towards technology was represented via three sub-scales, and had worse fit compared to SEM2, with CFI (0.895) and TLI (0.881) values slightly less than 0.9. The model that combined all the constructs of interest, SEM4, showed the worst fit with the lowest CFI (0.880) and TLI (0.866) values of all the models.

Additionally, path analysis across all models showed that the TAM predictors, VCS perceived usefulness and VCS perceived ease-of-use, were the only factors with significance for modeling attitude toward VCS. Further, perceived ease-of-use was a stronger predictor of attitude toward VCA than perceived usefulness. Attitude toward VCS remained a significant predictor of VCS use in every model.

In the multiple linear regression analysis, VCS perceived usefulness, $F(1,183) = 23.88$, $p < .0001$ and VCS perceived ease-of-use, $F(1,183) = 66.63$, $p < .0001$ were found to be significant predictors, but not VA Use, $F(2,183) = 1.44$, $p = .24$ or negative attitudes toward technology, $F(1,183) = 0.40$, $p = .53$. Positive attitudes toward technology, $F(1,183) = 2.99$, $p = .09$ and anxiety toward being without technology, $F(1,183) = 2.90$, $p = .09$ were found to be marginally significant effects. Regression diagnostics found that the model met all necessary assumptions, and the variance inflation factors (VIFs) were checked to protect against multicollinearity. The results of the regression indicated that the model explained 58.7% of the variance.

3.3 Discussion

From interviews with two groups of drivers that differed in their frequency of in-vehicle VCS use, the focus group study identified attitude towards technology as a factor that may influence the adoption of in-vehicle VCS whereas prior research indicated that usage of VAs (in non-driving contexts) influenced usage of in-vehicle VCS. These findings informed the design of a survey study which found perceived usefulness and perceived ease-of-use to be significant predictors of attitude toward in-vehicle VCS, which in turn significantly predicted actual use of in-vehicle VCS.

3.3.1 Perceptions of usefulness and ease-of-use

As mentioned above, the structural equation models that were built showed perceived usefulness of VCS and perceived ease-of-use of VCS to be significant predictors of attitude toward VCS. Path analysis results also showed these two factors to be significant predictors of attitude toward VCS; perceived ease-of-use was shown to be a particularly strong predictor. Results of the multiple linear regression analysis reflected these findings. These align with the first hypothesis (Section 3.2) as well as findings of previous literature (Koon et al., 2020; Lee, Mehler, et al., 2015; Lee, Reimer, et al., 2015) that have indicated that perceptions of a system's utility and ease-of-use play major roles in the adoption of said system. Also, the modified version of TAM that the SEMs used was found to be an appropriate framework for modeling acceptance of in-vehicle VCS, and thereby confirming the findings of Lee, Reimer, et al (Lee, Reimer, et al., 2015).

Given the influence that perceptions of usefulness and ease-of-use have on attitude towards in-vehicle VCS, it is imperative to continue to refine our understanding of these complex and nuanced factors. The driving environment is unique in not only its critical nature, but also in the variety and scale of demands that it places on the operator of the vehicle. Therefore, it is reasonable to assume that factors that constitute perceived usefulness and perceived ease-of-use of in-vehicle systems, differ from those that constitute perceived usefulness and perceived ease-of-use in non-driving environments.

The above findings also underscore the importance of designing in-vehicle VCS with a focus on interface usability, as highlighted by the findings of Kim & Lee (2016). Given the multi-modal nature of these systems, attention will need to be paid to all the components that comprise in-vehicle VCS, including voice command interaction, voice recognition accuracy, and accompanying displays.

3.3.2 Role of acceptance of VAs

The second structural model (SEM2), which was built with perceived usefulness of VCS, perceived ease-of-use of VCS, and VA use as predictors of attitude toward VCS, showed worse fit than the model with that did not take VA use into account (SEM1). The path analysis results also show that VA use is not a significant predictor of attitude towards VCS. This was also found to be true in the results of the multiple linear regression analysis. This partially aligns with the expectations of the results laid out previously. However, tests of independence, via Chi-square for independence, between VA use and VCS use, χ^2 (12, N = 198) = 24.78, $p < .05$, and VA use and VCS satisfaction (Q15, one of the constituent variables of attitude toward VCS), χ^2 (12, N = 198) = 24.59, $p < .05$, show that there is a relationship between VA use and VCS use and between VA use and VCS satisfaction.

There results suggest that while there appears to be a relationship between a person's VA usage and VCS usage, the former might not influence the attitude that person has toward VCS. Kim &

Lee’s (2016) suggested that prior experience with voice interfaces affect many aspects of user resistance to switching to in-vehicle VCS, including perceived value of the latter system. Therefore, it is possible that VA use instead has a mediating effect on factors that are strong predictors of attitude towards VCS or VCS use.

3.3.3 Attitude toward technology

The focus group study identified attitude towards technology as the main differentiator between drivers than used in-vehicle VCS frequently and those that did not. However, the structural equation modeling exercise showed models which included attitude toward technology subscales (positive, negative, and anxiety/dependence), namely SEM3 and SEM4, having worse fit. Results of the multiple linear regression did however show borderline significant relationships between positive attitudes toward technology and attitude toward VCS as well as anxiety about being without technology and attitude toward VCS.

Similar to VA use, it is possible that attitude towards technology does not have a direct effect on an individual’s attitude toward in-vehicle VCS but rather has an mediating effect one of the other factors that predict attitude towards these systems. Godoe & Johansen’s (2012) found that while general attitude toward technology plays a key role in the acceptance of new technology, if specific characteristics of a system, such as perceived usefulness and perceived ease-of-use, are too low, the system will be rejected regardless of attitude. This aligns with the expectations of results highlighted in Section 3.2 and with the results of the model testing exercise.

To the best or our knowledge, no prior work of research has investigated the role of attitude toward technology in the adoption of in-vehicle VCS. These results emphasize the need to explore this relationship further.

Chapter 4

4.0 Driving Simulator Study Design

4.1 Motivation and background

As mentioned in previous chapters, in-vehicle VCS have the potential to create a safer experience as these systems are not as visually or manually demanding as systems that require manual control (Putze & Schultz, 2012). Other than impacting the effectiveness of in-vehicle VCS, voice recognition accuracy has been found to be an important safety factor as drivers tend to physically move closer to the device or microphone when their voice commands are not understood, which leads to more frequent lane departures (Kun et al., 2007).

Low accuracy in these systems can be in part attributed to these systems' "lack of noise robustness" (Watanabe et al., 2017). Systems that lack noise robustness, or in other words, are noise-sensitive, are vulnerable to accuracy degradation when background noise in present. This combined with the fact that there is a high amount of ambient noise in vehicles (Czap & Pinter, 2018), a lot of which can be beyond the control of the driver, translates into many in-vehicle VCS experiencing reduction in accuracy when on the road which negatively impacts the adoption of these systems. Wu et al. (2015) conducted on-road contextual interviews to assess the impact of in-vehicle VCS on driver distraction and found that drivers that encountered errors with these systems often reverted to visual-manual interactions to accomplish their tasks. A previous Wizard of Oz study compared a noise-robust VCS to a noise-sensitive VCS in the presence of background noise where accuracy of the former system remained unaffected but degraded in the latter, and found that, unsurprisingly, user acceptance was higher for the former system (Sokol et al., 2017). Thus, it appears that low in-vehicle VCS accuracy negatively impacts how users perceive these systems. Though research about noise reduction techniques in speech recognition is advancing (Zheng et al., 2020), in-vehicle VCS that operate at 100% accuracy all the time is unlikely to be a reality any time soon. Therefore, it is important to explore mechanisms that can mitigate the negative effects of in-vehicle VCS accuracy degradation when background noise is present.

One such mechanism that warrants exploration is system feedback about context-dependent changes in accuracy. A potential implementation of this mechanism might be the in-vehicle VCS appropriately notifying the driver about a possible degradation in accuracy when it detects background noise. According to Norman & Draper (1986), system feedback about its state positively impacts user perception and reduces cognitive load. Lee & See (2004) also argue that understanding the possible influence of a system's environment on its performance may allow users to appropriately adjust their expectation and level of trust in the system. In evaluating context-aware voice interfaces for ambient assisted living, Vacher et al. (2015) stress the importance of adapting "the feedback strategy…to the abilities of the user and the context of interaction". While various aspects of in-vehicle VCS voice recognition continue to be researched, the effect of context on fluctuations in accuracy and how that impacts user perception remain largely unexplored. Though Sokol et al. (2017) introduced background noise as context to explain the accuracy degradation to the drivers, they did not investigate the role of system feedback in combination with contextual information. Thus, feedback from the in-vehicle VCS about context-dependent degradation might mitigate negative effects of decreased accuracy on user acceptance and performance.

To explore the abovementioned idea, a third study in the form of a controlled experiment using a driving simulator had been planned as a part of this thesis to explore the following research questions:

How are driving behavior and driver acceptance of in-vehicle VCS affected by

- (RQ1) Degrading VCS accuracy when background noise is present vs. absent?
- (RQ2) VCS feedback about degraded accuracy when background noise is present?

The proposal for this simulator study was originally approved by University of Toronto's Office of Research Ethics in August 2018 (REB Human Protocol Number 36315). The approval was renewed in June 2019 and April 2020.

Shortly after the commencement of this study (sessions had been run with several pilot participants and one paid participant), University of Toronto put all human-subject research on hold as a part of its response to the COVID-19 pandemic. As a result, this study was suspended in March 2020, and at the time of writing, the above-mentioned safety measures were still in place. The rest of this chapter details the completed and planned efforts for this driving simulator study. Future research about in-vehicle VCS can hopefully utilize the work described below.

4.2 Planned methods

A driving simulator study had been planned to explore the research questions identified in section 4.1. In the study, recruited participants would have completed several drives in a simulated rural environment while issuing commands to a four different Wizard of Oz in-vehicle VCS. The environment of a driving simulator was deemed the most appropriate as it would not only ensure consistent driving conditions (e.g. lighting, weather, traffic, etc.) across different drives and between different participants, but it would also allow for the controlled introduction of background noise, sometimes in conjunction with specific traffic events (e.g. lead vehicle braking), and seamless VCS swaps between drives. The Wizard of Oz methodology, which presents a system as autonomous to the user when in fact some or all its responses are being simulated by an individual or team of experimenters, was also chosen to ensure consistent and time responses from the different VCS.

4.2.1 Experiment design

This study was designed to utilize a within-subject design with one factor (VCS condition) consisting of four levels. Participants would undertake 4 experimental drives in the simulator, on the same route, each with a different VCS condition. The VCS conditions differed in terms of (a) whether background noise was present at certain points during the drive when the participant gave the system a command, and how the system's accuracy degraded in relation to the background noise (to address RQ1), and (b) whether the VCS notified the user about the degradation in accuracy (to address RQ2). The order of VCS conditions was fully counterbalanced which resulted in 24 (4!) unique orders. Table 6 presents a summary of the VCS conditions; more details can be found later in this chapter (Section 4.2.5 and Figure 5).

Table 9. Summary of planned simulator study VCS conditions

VCS condition	Noise	Accuracy degradation	Degradation notification	Accuracy
Context-less degradation 1 (CLD1)	No	System degrades for no reason (in the absence of noise)	No	60% (i.e., 6/10 tasks succeed; 4/10 tasks fail)
Context-less degradation 2 (CLD2)	Yes	System degrades randomly, both in the presence and absence of noise	No	60%
Context-dependent degradation (CDD)	Yes	System degrades in presence of noise	No	60%
System-aware context-dependent degradation (SACDD)	Yes	System degrades in presence of noise	Yes	60%

4.2.2 Participants

The study had planned to recruit 24 participants (12 female, 12 male) between the ages of 20 and 55. Eligible participants would have been required to be non-novice drivers (3+ years of driving experience), have a valid G driver's license issued by the province of Ontario, self-report to have good hearing as well as either uncorrected vision or being able to wear contact lenses, and having driven a minimum of 1600 km in the last 12 months. The desired sample size was based on the number of unique experimental conditions that would have had to be run to achieve full counterbalancing, as calculated in Section 4.2.1. The recruitment poster (Appendix I) had been posted on Kijiji, Craigslist, and Facebook and several individuals had completed the online screening questionnaire (Appendix J) at the time that this study was suspended.

Sessions were expected to last between 2.5 to 3 hours and participants would have been compensated at a rate of 15 CAD/hour with an additional 5 CAD "VCS task performance bonus". The impetus of a bonus was included to motivate participants to give the VCS interactions importance and pay attention to prompts from the experimenter. All participants that completed the experiment would have been paid the full bonus.

4.2.3 Apparatus

A NADS quarter-cab MiniSim™ Driving Simulator was to be used for the study (Figure 3). This fixed-base simulator has three 42-inch widescreen displays, creating a 130-degree horizontal and 24-degree vertical field of view at a 48-inch viewing distance. The experiment was developed using the MiniSim Software Suite while the driving scenarios were created using the Interactive Scenario Authoring Tool. The roadways for the scenarios were created using the Tile Mosaic Tool.

The four experimental VCS were to be presented on a Microsoft Surface Pro 3 positioned to the right of the simulator's dashboard. Two specialized Python applications were developed to provide realistic Wizard of Oz simulations of the VCS; the first application was programmed to run on the Surface Pro to display static webpages (developed with HTML, CSS, and JavaScript) that displayed various states of the VCS and task results, and to play the "listening" chimes after participants said the activation phrase ("Hey VC" or "OK, VC") whereas the second application was developed to run on a desktop computer, specifically the Dlab computer mentioned below, which was connected to both the Surface Pro and the MiniSim computer via an internal network. The latter was designed to allow the experimenter to act as the Wizard and display the appropriate webpage on Surface's screen by controlling the former. The purpose of the second application's connection to the MiniSim computer was to capture the simulator frame number each time the experimenter triggered an event. The captured frame numbers would have been used during analysis to create a timeline that unified both MiniSim and VCS events. For the duration of the experiment, a second person would be seated at the Dlab computer to act as the proverbial Wizard and operate the VCS to respond appropriately to the participant's actions.

Clips of Michael Jackson's Billie Jean was used as background noise for the design of this experiment and was played through the MiniSim speakers. The music sample was purchased through Apple's iTunes for a previous study designed and conducted at the Human Factors and Applied Statistics lab. Two audio files from Google's Material Design (cite) were used as acknowledgement chimes for the "normal listening" and "degraded listening" states. The study had also planned to use electrocardiogram (ECG) and galvanic skin response (GSR) sensors and amplifiers developed by Becker-Meditec to record participant’s physiological state at a rate of 240 Hz. This data would have recorded using the Dlab experimental recording software, synced to simulator events through frame data collected via a network link between the Dlab computer and MiniSim. A head mounted Dikablis Glasses 3 eye tracker would have been used to collect gaze data.

4.2.4 Driving task

Participants were to be instructed that their primary task was to drive safely through the environment while following a lead vehicle and maintaining the speed limit of 50 mph. About 20 seconds after the completion of the VCS interaction tasks (see Section 4.2.6), participants would have been prompted to pull over to the side of the road when they thought it was safe to do so. The drive would have ended upon the participant’s vehicle coming to a complete stop.

The 4 experimental drives would have occurred on the same road in a rural setting at daytime with sparse oncoming traffic. The route included some gentle curves but no turns at intersections. Some parked cars and farm buildings were present as visual clutter. Each of these drives was expected to take around 6 minutes to complete. Two shorter dummy drives, on a different route than the one used for the experimental drives, were included to avoid more than two almost-identical back-to-back drives, and to minimize learning effects. Including a short training drive, each participant would have undertaken a total of 7 drives.

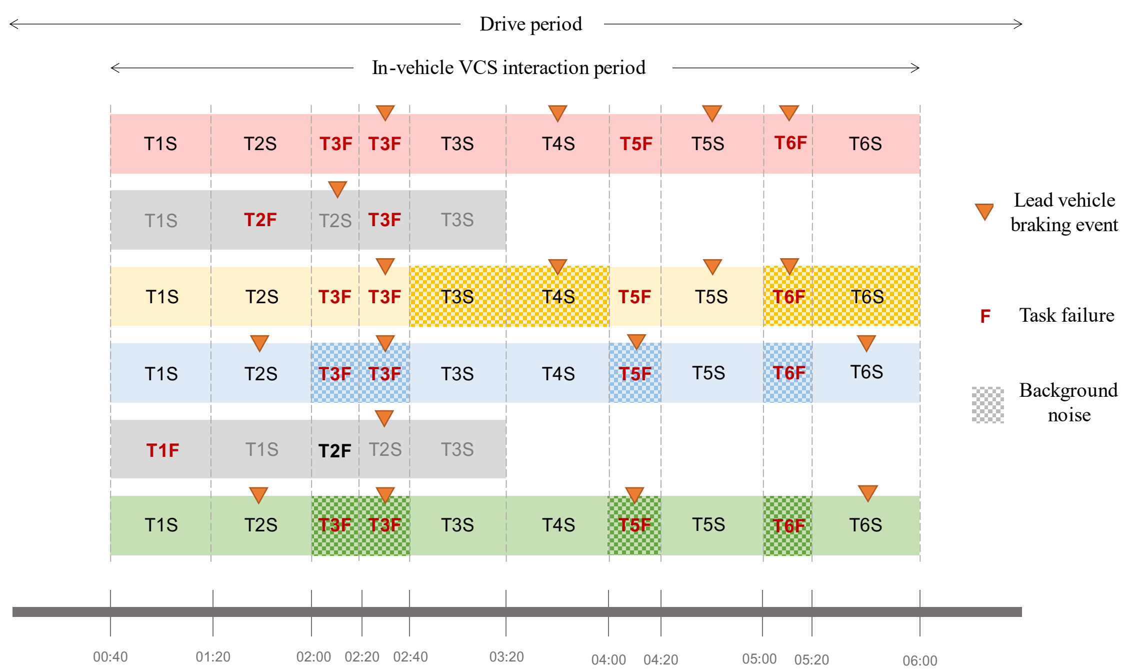
The lead vehicle that the participants would have been asked to follow was configured to maintain a 2.5 second headway between itself and participant’s vehicle. Four lead-vehicle braking events were set to occur at different points in the drive; each of these occurrences were designed to overlap with the participant issuing a voice command to the VCS. Half of these commands were set up to result in failures while the rest would result in successes. The points at which the braking events were set to occur, and their overlap with VCS task, as well as the presence/absence of noise can be found in Figure 6.

4.2.5 VCS tasks and conditions

While carrying out the primary task of driving in the simulator, participants would have taken on the secondary task of interacting with a VCS condition, by accomplishing various tasks via voice command, in each of the drives they undertook.

In each of the experimental drives, participants would have issued a total of 10 commands, while in the shorter dummy drives, they would have issued a total of 5 commands. All VCS were designed to emulate 60% accuracy; in the experimental drives, this translated in to 6/10 commands resulted in successes while the remaining 4 commands resulted in failures. Tasks were designed to mimic VCS tasks that users might perform in a vehicle and broadly separated into three categories: communication, media, and navigation tasks. A full list of the tasks designed for this study can be found in Appendix G.

Figure 5. VCS conditions showing task failures, lead vehicle braking events, and background noise.

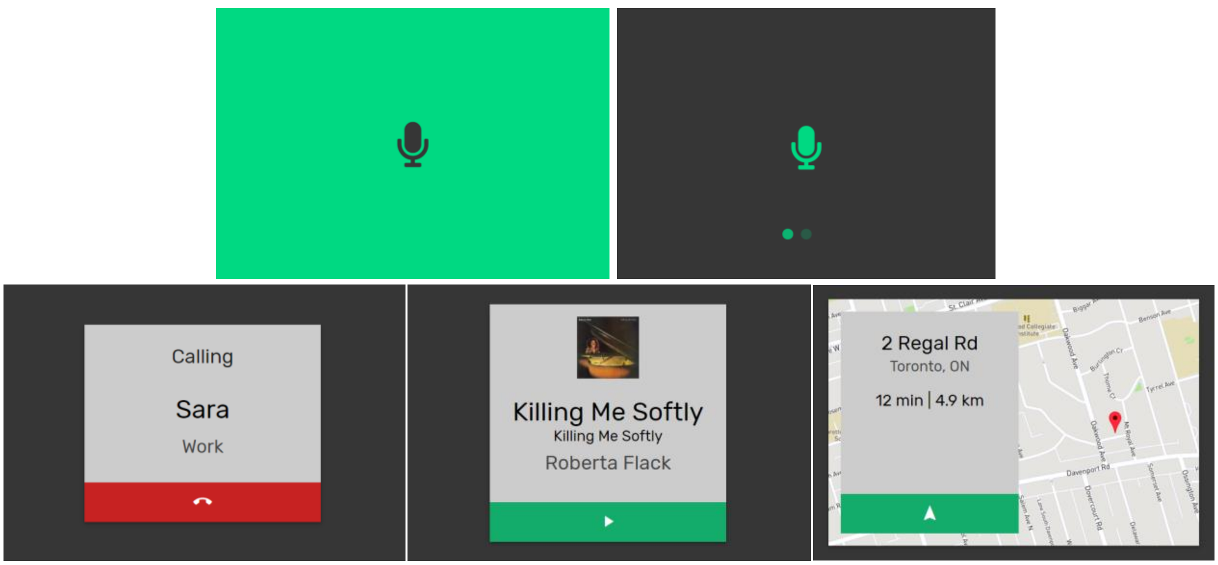


The experimental drives were designed to time the occurrence of road events, task failures, and where applicable, background music in multiple ways so that the effect of combination of various factors could be examined. Specifically, the overlap of task failures and lead-vehicle braking events for the different VCS conditions was of interest. Figure 5 illustrates the occurrences of these events.

In all four conditions, the default state of the VCS was designed to be a standby state (Figure 6a). Upon the utterance of the activation phrase by the participant, the VCS would transition to a "listening" state (Figure 6b); it would remain in this state while the task command was issued. It would then transition to show the predetermined result (depending on whether the task was designed to succeed or fail). Figures 6c, 6d, and 6e show examples of a communication task result, a media task results, and a navigation task result respectively.

Figure 6. VCS screens showing (a) normal standby state, (b) normal listening state, (c) communication task result, (d) media task result, and (e) navigation task result.

(a) (b)



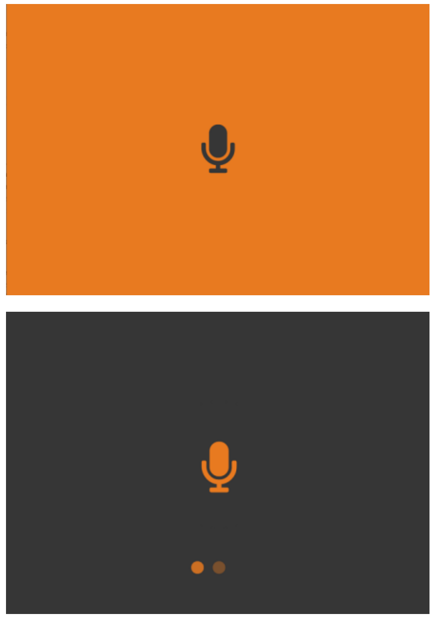
(c) (d) (e)

In three (CLD1, CLD2 and CDD from Table 5) of the four conditions, the VCS were not designed to notify the user about accuracy degradation, regardless of the presence of background noise and its co-occurrence with task failures. As a result, these three VCS conditions would have only shown the above-mentioned states.

In the SACDD condition, which was designed to notify the user when accuracy degraded in the presence of background noise, the VCS had two additional states: a degraded version of the standby state and a degraded version of listening state. Figure 7 shows these states.

Figure 7. VCS screens showing (a) degraded standby state, and(b) degraded listening state.

(a)



(b)

In preparation for the experiment, 24 protocols - one for each participant - had been created where VCS conditions and order of tasks were randomized. Appendix H presents one such protocol.

4.2.6 Planned procedure

Upon arrival at the experiment location, each participant was to be provided with written and verbal instructions regarding the driving simulator study and the procedures it entailed. To minimize the rate of withdrawal and set up appropriate expectations, recruited participants would have been emailed a copy of the same written instructions upon indicating intent to participate. Once the participant's consent was obtained, the experiment would officially commence with the participant filling out the pre-experiment questionnaire which asked them about demographic information, driving history, and in-vehicle technology use including in-vehicle VCS.

Next, the participant would have been ushered into the room with the driving simulator where the VCS operator would have been introduced as a collaborating experimenter who would be monitoring data collection during the length of the experiment. Then, they would have been instructed to affix physiological measure (ECG and GSR) sensors on their person with the help of a reference image that illustrated the correct locations of said sensors. Once properly seated in driving simulator, with necessary adjustments to seat height and distance, participants would have been assisted with putting on the head-mounted eye-tracker. After ensuring that signals from all external experimental devices were being successfully captured on the DLab computer, the eye-tracker was calibrated to track the participants pupils.

Once all the necessary experimental equipment was correctly set up, the participant would have received brief verbal introduction to the experiment and instructions about their main task, which was to drive safely at the posted speed limit (50 mph) while following the vehicle in front of them, and interacting with the VCS they would encounter during the study.

Specifically, the participant would have been told that they would be interacting with a few different VCS that were being developed by a third party and that differed slightly based on the underlying algorithm. The purpose of this instruction would have been to prevent biases toward the simulated VCS, stemming from the belief that they had been developed by the experimenter. They would have then been instructed to trigger in-vehicle VCS interactions by saying the phrase “Hey VC” or “OK VC”, when prompted by the experimenter with a task. They would have been told that this phrase would place the in-vehicle VCS in “listening” state after which they could give it the rest of the command, for example “Show me directions to the University of Toronto”. Participants were told that they did not need to use the exact language of the prompt in order to have the VCS understand them. In addition, once the in-vehicle VCS displayed a task result, participants were instructed to say “confirm” to indicate that returned result was correct, i.e., the system had correctly understood and processed the command that had just been issued, and to say “cancel” to indicate that the returned result was erroneous, i.e., the system had failed to correctly understand and/or process the verbal request.

Next, the participant would have undertaken a 5-minute training drive to become accustomed to the driving simulator and simulated VCS. They would have encountered 6 tasks, out of which two would have failed on the first attempt but would have been successful on the second attempt (Appendix H). After the training drive, participants were to be given a short break where they would had the opportunity to ask questions, adjust the driver’s seat, as well as the experimental equipment on their person in order to minimize the need for adjustments once the experimental drives were underway.

Following the training drive, participants would have undertaken the 4 experimental drives, interspersed with two additional dummy drives. At the end of every drive, participants would been given a 5-minute break during which they would have also completed the post-drive questionnaire (Appendix M) that was expected to take under 2 minutes. Following the end of the last experimental drive, the participant would have been instructed to remove the physiological sensors on their person, take off the head-mounted eye-tracker, and exit the driving simulator. They would have been ushered out of the simulator room where they would have completed the post-experiment questionnaire (Appendix N); this was expected to take up to 20 minutes. Finally, the participant would have been thanked for their time and participation, compensated in cash, and asked to sign a receipt.

4.3 Planned measures and analysis

This study had planned to use various measures to assess driving performance and VCS acceptance. Table 7 below summarizes how the dependent measures would have been collected and what construct they would have been used to represent.

Post processing, the data would have been analyzed using appropriate methods, including linear regression, to describe the measures and the relationships between them.

Table 10. Summary of dependent measures that were to be analyzed

Construct	Dependent Measures	Data Source
Acceptance	Usefulness	Post-drive questionnaire
	Satisfaction	Post-drive questionnaire
Driving Performance	Avg. Speed	MiniSim
	SD Speed	MiniSim
	SD Lane Position	MiniSim
	Avg, Acceleration Release Time	MiniSim
	Avg. Transition Time	MiniSim
	Avg. Brake Response Time	MiniSim
	Avg. Max. Deceleration	MiniSim
	Avg. Min. Time-to-collision	MiniSim
Workload	NASA TLX	Post-drive questionnaire
	Galvanic Skin Response	DLab via physiological sensor
	Heart Rate	DLab via physiological sensor
Glances to display	Avg. Glance Duration	DLab via head-mounted eye-tracker camera
	Rate of glances ≥ 2s, ≥ 1.5s, and < 1.6s	DLab via headmounted eye-tracker camera

Chapter 5

5.0 Conclusion and Future Work

5.1 Contributions

In the driving environment, VCS offer the potential of increased road safety as well-designed VCS can translate to drivers continuing to keep their eyes on the road and hands on the steering wheel while still interacting with in-vehicle technology. In order to design effective in-vehicle VCS, it is important to ascertain how and why drivers use the systems. This thesis conducted two studies to gain and understanding of current in-vehicle VCS usage patterns and the factors that can explain these patterns. The focus group highlighted the role of several factors including attitude toward technology and use of other voice technology in the acceptance of these systems, and the survey described the relationship between factors by using TAM as a base framework. While more research is required to paint a fuller picture of predictors of adoption and use of in-vehicle, the studies conducted as part of this thesis identified some predictors that should be investigated further.

5.2 Limitations

There were some aspects of the focus group and survey studies that must be recognized as limitations.

While the focus group study was advantageous in some regards, group dynamics could have led to certain individuals not participating as much as others in the discussions. While the facilitator of the prompted participants who shared less, there is possibility that certain ideas or experiences were not discussed. Individual interviews with in-vehicle VCS users might have mitigated this issue in part. Given the limited sample size of focus groups, multiple sessions with the different types of users would have produced more generalizable findings. In addition, interrater reliability was not computed for the qualitative analysis of the focus group.

The final sample size for the survey was not as large as originally planned (250-300) and hosting in on Mechanical Turk made it challenging to screen respondents thoroughly. At the time that the survey study was conducted, it was considered an exploratory study that was auxiliary to the planned driving simulator study. With research efforts being primarily focused on the setup of the latter, the design of the survey was less rigorous. As a result, important factors that impact in-vehicle VCS usage were not explored deeply and that certain questions were framed in sub-optimally, given the objectives of this research.

5.3 Future research

Future work should continue to explore factors that predict in-vehicle VCS usage and this domain is largely unexplored. Studies should examine differences in behaviour patterns across different segments of the population. While the findings of this thesis did not specifically explore the role of age in adoption of this technology, prior research indicates that the generational differences influence attitude toward and use of technology. In addition, exposure to and use of similar technologies, such as voice assistants, should be explored more deeply as this has been found to be influential in the adoption of voice technology in the driving environment.

Finally, due to world events, the research focus of this thesis had to change; the driving simulator study that was to constitute the preponderance of this thesis was suspended when COVID-19 was declared a pandemic. The study had aimed to investigate the role of context and impact of system feedback on driving performance and user acceptance of in-vehicle VCS had to be suspended after running only one participant. A future research project should continue or extend the planned simulator study to investigate the original research questions of thesis noted in Chapter 4; the findings of such a study could inform more effective designs for in-vehicle VCS.

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Appendices

Appendix A: Focus group study – Recruitment poster

Appendix B: Focus group study – Screening questionnaire

1. Do you speak English?
   a. Yes
   b. No

2. Are you between the ages of 25-50?
   a. Yes
   b. No

3. Please enter the month and year of your birth (MM/YYYY). For example, 12/1978:
   ____

4. What is your gender?
   a. Female
   b. Male
   c. Other
   d. Prefer not to answer

5. Do you currently have a valid government issued license?
   a. Yes
   b. No

6. How often do you drive a car or other motor vehicle?
   a. Almost every day
   b. A few days a week
   c. A few days a month
   d. A few times a year
   e. Never

7. Over the last year, how many kilometers did you drive?
   a. Under 1000
   b. Between 1,001 and 5,000
   c. Between 5,001 and 10,000
   d. Between 10,001 and 15,000
   e. Between 15,001 and 20,000
   f. Over 20,001
   g. None
   h. I don’t know

8. How often do you use in-vehicle voice command systems? For example: Ford Sync or Apple CarPlay.
   a. More than once a day
   b. About once a day
   c. A few times a week
   d. A few times a month

e. A few times a year
f. Tried it a few times and haven’t used it since
g. Never

9. Thank you for filling out this questionnaire. If you’re eligible for our focus group, we will contact you. Please enter your name and an email address and/or phone number that we can reach you at:
   a. First Name:
   b. Last Name:
   c. Email:
   d. Phone:

10. Preferred method of contact:
    a. Email
    b. Phone
    c. Either

Appendix C: Focus group study – Consent form

Participant Consent Form

Title: Focus group study to explore in-vehicle voice control system usage patterns and user experience

Investigators: Prof. Birsen Donmez, PhD PEng | Associate Professor
Department of Mechanical & Industrial Engineering
Faculty of Applied Science & Engineering | University of Toronto
Tel: 416-978-7399, Email: donmez@mie.utoronto.ca

Ms. Joey Chakraborty, MASc Candidate
Department of Mechanical & Industrial Engineering
Faculty of Applied Science & Engineering | University of Toronto
Tel: 519-497-5427, Email: joeych@mie.utoronto.ca

You are being asked to take part in a MASc research study from Human Factor and Applied Statistic Lab at the University of Toronto. Before agreeing to participate in this study, it is important that you read and understand the following explanation of the proposed study procedures. The following information describes the purpose, procedures, benefits, discomforts, risks and precautions associated with this study. In order to decide whether you wish to participate or withdraw in this research study, you should understand its risks and benefits to be able to make an informed decision. This is known as the informed consent process. Please ask the investigator to explain any words you don't understand before signing this consent form. Make sure all your questions have been answered to your satisfaction before signing this document.

Purpose

This study aims to understand subjective user experiences and usage patterns of drivers that use in-vehicle infotainment systems. As a participant you will be asked to:

1. Fill out a questionnaire
2. Engage in the focus group and share your experiences and ideas

Procedure

There are 3 parts to this study:

1. <u>Pre-focus group questionnaire</u>: You were asked to fill out a questionnaire to provide information about your driving habits, attitude toward technology, the vehicle and in-vehicle voice control system you use, and demographics.
2. <u>Focus group:</u> You will be asked a series of questions regarding your views, experience and ideas related to in-vehicle infotainment and voice control systems. You will also be asked to participate in an exercise to brainstorm the ideal in-vehicle voice control system.
3. <u>Compensation</u>: You will be compensated with cash and will sign a receipt of your compensation.

Risks

There is minimal risk involved in this study. You will be asked to share your experiences with in-vehicle voice control systems as well and thoughts and ideas surrounding them.

Benefits

The most important benefit is your contribution to research in improving the designs of in-vehicle technology. You will also gain experience with academic research.

Compensation

The experiment is expected to last for approximately two hours. At the end, you will receive payment at the rate of $14/hr. Hence, the maximum total compensation is $28 ($14 x 2).

Confidentiality

All information obtained during the study will be held in strict confidence. No names or identifying information will be used in any publication or presentation. You will be identified with a study number only, and this study number will only be identifiable by the investigators. No information identifying you will be transferred outside our research facilities.

Please be advised that we will audio-record and take notes during the session which will be used for analysis purposes only.

( ) I consent to having my video released for publications and public presentations
( ) I DO NOT consent to having my video released for publications and public presentations

Participation

Your participation is voluntary, and you may refuse to participate, may withdraw at any time, and may decline to answer any question or participate in any parts of the procedures/tasks – all without negative consequences. If you choose to withdraw at any point during the experiment, your data will be deleted. Only your name will be kept on record.

Location

The experiment will be conducted in room MB 101 at Lassonde Mining Building (MB), 170 College Street, Toronto, ON M5S 3E3.

Questions

You can contact the Office of Research Ethics at ethics.review@utoronto.ca, or 416-946-3273, if you have questions about your rights as a participant. If you have any general questions about this study, please call 519-497-5427 or email joeych@mie.utoronto.ca

Consent

I have had the opportunity to discuss this study and my questions have been answered to my satisfaction. I consent to take part in the study with the understanding I may withdraw at any time. I have received a signed copy of this consent form. I voluntarily consent to participate in this study

______________________	______________________	______________________
Participant’s Name (please print)	Signature	Date

I confirm that I have explained the nature and purpose of the study to the participant named above. I have answered all questions.

______________________	______________________	______________________
Investigator’s Name	Signature	Date

Appendix D: Focus group study – Pre-focus group questionnaire

Pre-Focus Group Questionnaire

You are invited to participate in a focus group conducted by the Human Factors and Applied Statistics Lab (Director: Prof. Birsen Donmez) at the University of Toronto.

The goal of this research is to better understand usage patterns and user experiences of voice control systems found in vehicles today. The following questionnaire will help supplement the data we will collect during the focus group.

Please note that all information collected will be held in the strictest confidentiality. Personal data will be stored securely in the Human Factors and Applied Statistics Lab's secure password-protected Network Attached Storage at the University of Toronto. Under no circumstances will personal data be revealed to any third party, for any purpose. If you are not chosen for this experiment and do not want to be informed for future driving study in our lab, your information will be deleted.

Please note that personal contact information will be used solely for the purpose of future research opportunities at our lab, if you so desire.

If you have any questions or concerns you would like to be addressed before or after completing this questionnaire, please contact the investigator at hfast.lab@gmail.com.

General Information

1. First name:
2. Last name:
3. Age:
4. Gender:
    a) Male
    b) Female
    c) Other
    d) Prefer not to answer
5. If you are interested in participating in future research at the Human Factors and Applied Statistics Lab, please indicate below (if you are not interested, you can skip this question).

    ☐ I am interested in participating in your future research; please contact me when opportunities become available.

    ☐ I am <u>not</u> interested in participating in your future research.

Driving History

6. Do you currently have a valid state issued driver's license?
   a. No (Please inform the research team)
   b. Yes

7. How often do you drive a car?
   a. Almost every day
   b. A few days a week
   c. A few days a month
   d. A few times a year
   e. Never

8. Over the last year, how many miles did you drive?
   a. Under 1000
   a. Between 1,001 and 5,000
   b. Between 5,001 and 10,000
   c. Between 10,001 and 15,000
   d. Between 15,001 and 20,000
   e. Over 20,001
   f. None (Please inform the research team)
   g. I don't know

9. Do you normally wear corrective lenses when driving?
   a. No
   b. Yes - glasses
   c. Yes - contacts

10. Compared with others your age, how would you rate your overall vision? (If you wear glasses or contacts, rate your corrected vision when you are wearing them.)
    a. Excellent
    b. Good

c. Mean
d. Fair
e. Poor

11. Do you wear a hearing aid?
    a. No
    b. Yes

12. Compared with others your age, how would you rate your overall hearing?
    a. Excellent
    b. Good
    c. Mean
    d. Fair
    e. Poor

13. On a scale of 1 to 10 with 1 being very unsafe and 10 being very safe, how safe a driver do you think you are?

    1 2 3 4 5 6 7 8 9 10

    Very Unsafe Very Safe

14. In the past five years, how many times have you been stopped by a police officer and received a **warning** (but no citation or ticket) for a moving violation (i.e. speeding, running a red light, running a stop sign, failing to yield, reckless driving, etc.)?

    Enter a number: __________ (Enter 0 for none.)

15. In the past five years, how many times have you been stopped by a police officer and received a **citation or ticket** for a moving violation?

    Enter a number: __________ (Enter 0 for none.)

16. In the past five years, how many times have you been in a **vehicle crash** where you were the driver of one of the vehicles involved?

Enter a number: __________ (Enter 0 for none.)

Technology

17. On a scale of 1 to 10, with 1 being very inexperienced and 10 being very experienced, how would you rate your level of experience with technology (e.g. cell phones, automatic teller machines, digital cameras, computers, etc.)?

1 2 3 4 5 6 7 8 9 10

Very Inexperienced Very Experienced

18. Some people prefer to avoid new technologies as long as possible while others like to try them out as soon as they become available. In general, how would you rate yourself as being an avoider or an early adopter of new technology?

1 2 3 4 5 6 7 8 9 10

Avoid as long as possible Try as soon as possible

19. How would you rate your overall level of trust in technology?

1 2 3 4 5 6 7 8 9 10

Very Distrustful Very Trustful

20. How would you rate your level of trust in **established** car technologies (e.g. anti-lock brakes, automatic transmissions, air bags, etc.)?

1 2 3 4 5 6 7 8 9 10

Very Distrustful Very Trustful

21. How would you rate your level of trust in **new** technologies that are being introduced into cars?

1 2 3 4 5 6 7 8 9 10

Very Distrustful Very Trustful

22. How would you rate your ability to learn how to operate new technologies?

1 2 3 4 5 6 7 8 9 10

Very Poor Very Good

23. On mean, how often do you use an electronic navigation system in a car or truck (using a built-in navigation system, portable navigation unit or a smart phone)?

a. More than once a day
b. About once a day
c. A few times a week
d. A few times a month
e. A few times a year
f. Never

24. How often do you use a voice command interface in **any environment** (on a smart phone, in your car, or some other voice enabled system such as speech to text translation software)?

a. More than once a day
b. About once a day
c. A few times a week
d. A few times a month
e. A few times a year
f. Never

25. How often do you use **in-vehicle** voice command interface systems? For example, embedded systems like Ford Sync or connected systems like Android Auto.

a. More than once a day
b. About once a day
c. A few times a week
d. A few times a month
e. A few times a year
f. Tried it a few times and haven't used it since
g. Never

The Vehicle You Drive

26. What is the make and model of the vehicle(s) you drive (ex. 2010 Honda Civic)? If you regularly drive more than one, please list details of all vehicles.

____

____

27. What kind of voice control system do you use in the above-mentioned vehicle(s)?

____

____

Demographics

The following are standard questions that allow researchers to determine how representative the group of participants in a study is of the general population. Remember, filling out this questionnaire is voluntary. Skipping any question that makes you feel uncomfortable will not exclude you from the study.

28. Please describe the highest level of formal education you have completed:

a. Some high school or less
b. High school graduate
c. Some college
d. College graduate

e. Some graduate education
f. Completed graduate or professional degree (e.g. Masters, LCSW, JD, PhD., MD, etc.)

29. Are you: (Please circle all that apply)

a. A full-time student
b. A part-time student
c. Unemployed
d. Retired
e. Employed full time
f. Employed part time
g. A full-time caregiver (e.g. children or elder)
h. A part-time caregiver (e.g. children or elder)
i. None of the above

30. Please provide the city and province where you drive most often:

City: ________________________

Province: _____________________

Appendix E: Focus group study – Session slide deck

Welcome!

- Please read **consent form** and let us know if you have questions
  - If you are satisfied and consent to taking part, please sign
- Help yourself to water, coffee & Timbits
- Washrooms:
  - Men's: turn left and through double doors
  - Women's: turn left and through double doors, one level up and turn right
- We will wrap up by 12:30 pm
- We will have 2 scheduled breaks, and more if needed

Human Factors & Applied Statistics

1

Usage Patterns And User Experiences Of In-vehicle Voice Control Systems

A FOCUS GROUP

UNIVERSITY OF TORONTO

Joey Chakraborty
Suzan Ayas
Michelle Ji

2

As a focus group participant, we request you to…

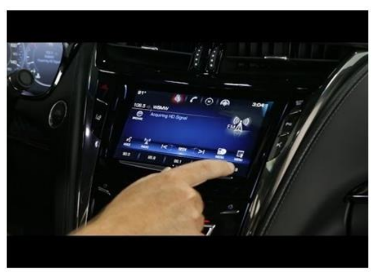
- Be candid and speak up
- Tell us about <u>your</u> experience and <u>your</u> view
- Share any ideas and thoughts that come to mind; don't worry about cost, reliability or realism

As a research team, we are interested in a range of perspectives and ideas, not consensus

3

Project Background

- Infotainment systems (video)

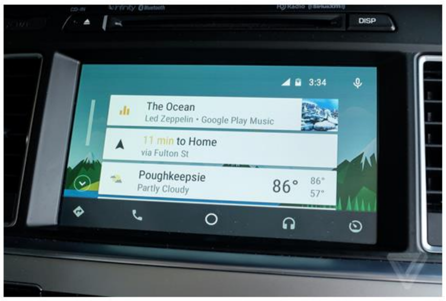


4

Connected Systems

EXAMPLES

Android Auto



Apple CarPlay

5

Embedded Systems

EXAMPLES

Tesla Model S

Chrysler UConnect

GMC Denali

Volkswagen Discover Media

Project Background

- Infotainment systems with voice control capabilities are becoming more commonplace in vehicles
- Goal of this focus group:

  To get a better understanding of
  - How and when people use in-vehicle voice command systems (VCS)
  - What these systems do well
  - What they don't do well

7

What tasks do you use in-vehicle VCS for?

- Communication
  - Calling or text messaging
- Navigation
- Entertainment
  - Music, radio, audiobooks, podcasts, games, social media, etc.
- Retrieving other information
  - Weather, traffic, sports, etc.
- Anything else?

8

What tasks do you avoid using in-vehicle VCS for?

- Communication
  - Calling or text messaging
- Navigation
- Entertainment
  - Music, radio, audiobooks, podcasts, games, social media, etc.
- Retrieving other information
  - Weather, traffic, sports, etc.
- Anything else?

9

When do you use in-vehicle VCS?

- What kind of situations or conditions? Please give us some examples

10

When do you avoid using in-vehicle VCS?

- What kind of situations or conditions? Please give us some examples

11

Break – 5 mins

UNIVERSITY OF TORONTO

12

What do in-vehicle VCS do well?

- Consider different aspects such as, but not limited to:
  - Ease of use
    - Voice commands, manual interaction
  - Intuitiveness
    - System feedback and display
  - System accuracy
  - Anything else?

13

Where do in-vehicle VCS fall short?

- Consider different aspects such as, but not limited to:
  - Ease of use
    - Voice commands, manual interaction
  - Intuitiveness
    - System feedback and display
  - System accuracy
  - Anything else?

14

How does the accuracy of in-vehicle VCS affect your usage?

- Please give us some examples

15

Has anything within the environment of the vehicle affected your use of in-vehicle VCS systems?

- What has your experience been like?

16

What if the in-vehicle VCS notified you when it experienced a drop in accuracy?

- Thoughts?

17

Break – 5 mins

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18

VCS Interface Design Feedback

- You will now play a few minutes of a driving game on a computer
- While you play, you will be shown two different designs of VCS interfaces
- Please tell us what you think of the different VCS designs

19

Thank You!

- Compensation & receipt signing
- We appreciate your time and input

20

Appendix F: Survey study - Questionnaire

Participant Consent

1) You are being asked to take part in a MASc research study from Human Factors and Applied Statistics Lab at the University of Toronto. Before agreeing to participate in this study, it is important that you read and understand the following explanation of the proposed study procedures. The following information describes the purpose, procedures, benefits, discomforts, risks and precautions associated with this study. In order to decide whether you wish to participate in or withdraw from this research study, it is important to understand the associated risks and benefits. This is known as the informed consent process.

   Purpose
   This study aims to understand subjective user experiences and usage patterns of drivers that use in-vehicle infotainment systems. As a participant you will be asked to fill out a survey questionnaire. This questionnaire will ask you to provide information regarding your driving habits, behaviours and perceptions toward various technologies, and demographics.

   Risks
   There is minimal risk involved in this study. You will be asked to share your experiences with in-vehicle voice control systems as well and thoughts and ideas surrounding them.

   Benefits
   The most important benefit is your contribution to research in improving the designs of in-vehicle technology. You will also gain experience with academic research.

   Compensation
   Participants who **complete** the survey will be paid 4 USD.

   Confidentiality
   All information obtained during the study will be held in strict confidence. No names or identifying information will be collected in this survey.

   Participation
   Your participation is voluntary. You may refuse to participate and may exit the survey at any time prior to submission in order to withdraw. **Please note that you may not withdraw from this survey once you have completed and submitted it.**

   Questions
   You can contact the Office of Research Ethics at ethics.review@utoronto.ca, or 416-946-3273, if you have questions about your rights as a participant. If you have any general questions about this study, please call 408-915-5427 or email joeych@mie.utoronto.ca

   ---

I consent to take part in the study with the understanding I may withdraw at any time. I voluntarily consent to participate in this study.

a. Yes
b. No

General Demographics

2) What is your sex?

a. Male
b. Female
c. Prefer not to say

3) What is your age? (e.g., 21)

4) What state/territory/province do you currently reside in? (e.g., NY)

5) What city do you currently reside in? (e.g. Toronto)

6) What type of driver's license do you currently hold?

a. Learner's license/permit
b. Full license
c. Other - Please specify:
d. I don't have a license

7) Approximately how many years have you been driving with at least a learner's license?

a. None
b. 1 - 5 years
c. 5 - 10 years
d. 10 - 15 years
e. 15+ years

8) How often do you drive?

a. Everyday
b. A few times a week
c. A few times a month
d. A few times a year

e. Never

9) What is the average distance you drive per week?

a. 0 - 10 km
b. 11 - 25 km
c. 26 - 50 km
d. 51 - 100 km
e. 101 - 150 km
f. 151 - 200 km
g. 201 + km
h. I don't drive

10) What type of motor vehicle do you drive most often?

a. Passenger car
b. Pick-up truck
c. Cargo van
d. Box/delivery truck
e. Bus, tractor trailer, vehicle with more than two axles
f. Other - Please specify:
g. I don't know

11) What is the make and model of the car you drive most frequently?

	Make (e.g. Subaru)	Model (e.g. Crosstrek)	Model Year (e.g. 2019)
Car			

12) What are your primary reasons for driving in a typical week?

	Please choose from the following options				
	Everyday	A few days a week	Once a week	Almost never	Never
a. Commuting (i.e., driving to work)					
b. Business (i.e., driving for work)					
c. Personal (e.g., shopping, social, outdoor, recreation)					
d. Social					
e. Outdoor/Recreation					

In-Vehicle Voice Command Systems

13) What kind of voice command system (VCS) do you use most often while driving?

a. Embedded (e.g. Ford Sync 3, etc.)
b. Connected (e.g. Apple CarPlay or Android Auto, etc.)
c. Your smartphone (e.g. iPhone, Android, etc.)
d. Other - Please specify:
e. I don't use one

14) How often do you use your in-vehicle VCS while driving?

a. Never
b. Rarely (i.e. I don't use it very often when I drive)
c. Occasionally (i.e. I use it every few times I drive)
d. Often (i.e. I use it almost every time I drive)
e. Always (i.e. I use it every time I drive)

15) Which of these statements best reflects how you feel about the VCS technology in the car you drive? (Select the closest answer.)

a. I'm very unhappy with the VCS technology

b. I like a few of the VCS features
c. I like most of the VCS features
d. I'm very happy with the VCS technology
e. I have no opinion

16) Do you think your VCS is accurate?

( ) 1 ( ) 2 ( ) 3 ( ) 4 ( ) 5 ( ) 6 ( ) 7 ( ) 8 ( ) 9 ( ) 10

Very Inaccurate Very Accurate

17) How did you learn to use the VCS technology in the car you drive? (Select all that apply)

a. A friend and/or family member
b. Websites and/or online videos
c. While interacting with the sales staff at the dealership
d. During delivery at the dealership
e. Vehicle manual
f. Other material provided by the manufacturer
g. Trial and error
h. By luck
i. Other - Please specify:
j. I don't know how to use the technology in my car

18) How would you prefer to learn about the various features of your car's VCS technology? (Select all that apply)

a. A friend and/or family member
b. Websites and/or online videos
c. While interacting with the sales staff at the dealership
d. During delivery at the dealership
e. Vehicle manual
f. Other material provided by the manufacturer
g. Trial and error
h. By luck
i. The car teaches me
j. Other - Please specify:

19) How often do you do each of the following by issuing commands to your in-vehicle VCS?

	Never	Rarely	Occasionally	Often	Always
a. Ask for directions					
b. Ask for the weather forecast					
c. Check traffic alerts					
d. Check news headlines					
e. Ask for calculations					
f. Find a local business					
g. Look up movie times					
h. Ask for a sports score					
i. Call a contact on your phone					
j. Look up events on your calendar					
k. Manage events on your calendar					
l. Look up measurement conversions					
m. Find recipes					
n. Play voicemail messages					
o. Play music/audiobooks/podcasts					
p. Set/cancel/manage alarms					
q. Control other smart devices					

20) Do you carry out any tasks not mentioned in the list above by issuing commands to your in-vehicle VCS?

a. No
b. Yes - Please specify:

21) Imagine your ideal in-vehicle VCS. Which of the following tasks would you like to accomplish with this system? (Select all that apply)

a. Ask for directions
b. Ask for the weather forecast
c. Check traffic alerts
d. Check news headlines
e. Ask for calculations
f. Find a local business
g. Look up movie times
h. Ask for a sports score
i. Call a contact on your phone
j. Look up events on your calendar
k. Manage events on your calendar
l. Look up measurement conversions
m. Find recipes
n. Play voicemail messages
o. Play music/audiobooks/podcasts
p. Set/cancel/manage alarms
q. Control other smart devices
r. Other - Please specify:

22) How likely are you to use your current VCS in the following situation?

	Never	Rarely	Occasionally	Often	Always
a. In bad traffic					
b. In bad weather					
c. When driving at high speeds					
d. When driving at low speeds					
e. When there are others in the car					
f. When I am mentally fatigued					
g. When the car is parked					
h. When I am in an unfamiliar place					

23) How much improvement would you like to see in the following factors in the in-vehicle VCS in your car?

	Needs no improvement	Needs some improvement	Needs a lot of improvement
a. Functionality (i.e. range of activities)			
b. Accuracy (i.e. correctness)			

24) Are there any other areas of improvements you can think of that you would like to see in your current in-vehicle VCS?

a. No

b. Yes - Please specify:

25) Comparing VCS interactions to visual/manual interactions (i.e., pushing buttons, turning knobs, moving a slider, operating touchscreen) with systems within the vehicle, please answer the following questions.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly agree
a. Using in-vehicle VCS while driving enables me to accomplish tasks more quickly as compared to visual/manual interactions with systems within the vehicle.					
b. Using in-vehicle VCS improves my driving performance as compared to visual/manual interactions with systems within the vehicle.					
c. Using in-vehicle VCS while driving increases my productivity as compared to visual/manual interactions with systems within the vehicle.					
d. Using in-vehicle VCS makes it easier to drive as compared to visual/manual interactions with systems within the vehicle.					
e. I find in-vehicle VCS useful to my driving as compared to visual/manual interactions with systems within the vehicle.					

26) Please rate the degree to which you agree or disagree with the following statements:

	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
a. Learning to operate in-vehicle VCS is easy for me.					
b. Interacting with in-vehicle VCS requires a lot of mental effort.					
c. I find it easy to get in-vehicle VCS to do what I want to do.					
d. I find in-vehicle VCS unnecessarily complex.					
e. I find in-vehicle VCS to be flexible to interact with.					
f. I find it takes almost no effort to become skillful at using in-vehicle VCS.					
g. Overall, I find in-vehicle VCS easy to use.					
h. I am suspicious of in-vehicle VCS's intent, action or outputs.					
i. In-vehicle VCS is dependable.					
j. In-vehicle VCS has integrity.					
k. In-vehicle VCS is reliable.					
l. I can trust in-vehicle VCS.					

27) How would you rate the overall level of trust in a traditional automaker (e.g., Ford, Toyota, GM, etc.) to produce an effective in-vehicle VCS when it comes to...

Privacy -5 ________________________[__]________________________ 5

Data protection -5 ________________________[__]________________________ 5

Functionality -5 ________________________[__]________________________ 5

Accuracy -5 ________________________[__]________________________ 5

28) How would you rate the overall level of trust in a high-tech company (e.g., Google, Apple, etc.) to produce an effective in-vehicle VCS when it comes to...

Privacy -5 ________________________[__]________________________ 5

Data Protection -5 ________________________[__]________________________ 5

Functionality -5 ________________________[__]________________________ 5

Accuracy -5 ________________________[__]________________________ 5

Voice Assistants (in non-driving environments)

29) Do you use a VA?

a. Yes *(takes use to Q 31)*
b. No *(takes user to Q 30)*

30) What are the reasons why you don't use Voice Assistants? (Select all that apply)

a. Privacy/security concerns
b. I don't find it useful
c. I don't know how to use it
d. Other - Please specify:

31) How often do you use VA?

a. At least once a day
b. At least once a week
c. At least once a month
d. At least once a year
e. Never

32) Which VA do you use most frequently?

a. Amazon Alexa
b. Siri
c. Google Assistant
d. Bixby
e. Cortana
f. Dragon Mobile
g. Extreme Personal Assistant
h. Hound
i. Other - Please specify:

33) Do you think your VA is accurate?

( ) 1 ( ) 2 ( ) 3 ( ) 4 ( ) 5 ( ) 6 ( ) 7 ( ) 8 ( ) 9 ( ) 10

Very Inaccurate Very Accurate

34) Why do you use your VA?

a. It's easy
b. It's fast
c. It's fun
d. Unable to type
e. Other - Please specify:

35) When do you use your VA?

a. When watching TV
b. When working
c. When cooking
d. When exercising or walking
e. When with friends or family

f. When in bed
g. When doing another activity
h. Other - Please specify:

36) How often do you do each of the following by issuing commands to your VA?

	Never	Rarely	Occasionally	Often	Always
a. Ask for directions					
b. Ask for the weather forecast					
c. Check traffic alerts					
d. Check news headlines					
e. Ask for a calculation					
f. Find a local business					
g. Look up movie times					
h. Ask for a sports score					
i. Call a contact on your phone					
j. Look up events on your calendar					
k. Manage events on your calendar					
l. Look up measurement conversions					
m. Finds recipes					
n. Play voicemail messages					
o. Play music/audiobooks/podcasts					

p. Set/cancel/manage alarms					
q. Control other smart devices					

37) Do you carry out any tasks not mentioned in the list above by issuing commands to your VA?

a. No
b. Yes - Please specify:

38) Imagine your ideal VA. Which of the following tasks would you like to accomplish with this system? (Select all that apply)

a. Ask for directions
b. Ask for the weather forecast
c. Check traffic alerts
d. Check news headlines
e. Ask for calculations
f. Find a local business
g. Look up movie times
h. Ask for a sports score
i. Call a contact on your phone
j. Look up events on your calendar
k. Manage events on your calendar
l. Look up measurement conversions
m. Find recipes
n. Play voicemail messages
o. Play music/audiobooks/podcasts
p. Set/cancel/manage alarms
q. Control other smart devices
r. Other - Please specify:

39) Comparing VA interactions to visual/manual interactions (i.e., typing, reading, selecting) with your phone or other systems, please answer the following questions:

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree

a. Using VA enables me to accomplish tasks more quickly as compared to visual/manual interactions with my phone or other systems.					
b. Using VA improves my task performance as compared to visual/manual interactions with my phone or other systems.					
c. Using VA increases my productivity as compared to visual/manual interactions with my phone or other systems.					
d. Using VA makes it easier to perform various tasks as compared to visual/manual interactions with my phone or other systems.					
e. I find VA more useful as compared to visual/manual interactions with my phone or other systems.					

40) Please rate the degree to which you agree or disagree with the following statements:

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
a. Learning to operate VA is easy for me.					
b. Interacting with VA requires a lot of mental effort.					
c. I find it easy to get VA to do what I want to do.					
d. I find VA unnecessarily complex.					
e. I find VA to be flexible to interact with.					
f. I find it takes almost no effort to become skillful at using VA.					
g. Overall, I find VA easy to use.					
h. I am suspicious of VA's intent, action or outputs.					
i. VA is dependable.					
j. VA has integrity.					
k. VA is reliable.					
l. I can trust VA.					

41) How would you rate the overall level of trust in a Silicon Valley tech company (e.g., Google, Apple, etc.) to produce an effective VA when it comes to...

Privacy -5 _________________________[__]______________________________ 5

Data Protection -5 _________________________[__]______________________________ 5

Functionality -5 _________________________[__]______________________________ 5

Accuracy -5 _________________________[__]______________________________ 5

General Technology

42) How did you learn to use the technology you use today? (Select all that apply)

a. A friend and/or family member
b. Websites and/or online videos
c. Trial and error
d. By luck
e. Other - Please specify:
f. I don't know how to use the technology

43) How would you prefer to learn about technology in general? (Select all that apply)

a. A friend and/or family member
b. Websites and/or online videos
c. Trial and error
d. By luck
e. The technology teaches me
f. Other - Please specify:

44) How often do you do each of the following?

	Choose from the following options									
	Never	Once a month	Several times a month	Once a week	Several times a week	Once a day	Several times a day	Once an hour	Several times an hour	All the time

a. Send, receive, and read e-mails (not including spam or junk mail)										
b. Check your personal email										
c. Check your work/school email										
d. Send/receive files via email										
e. Send/receive text messages on your mobile phone										
f. Make/receive phone calls on your mobile phone										
g. Read email on your mobile phone										
h. Get directions or use GPS on your mobile phone										
i. Browse the internet on your mobile phone										
j. Listen to music/podcasts on your mobile phone										
k. Take pictures/record video on										

your mobile phone										
l. Use apps (for any purpose) on your mobile phone										
m. Search for information on your mobile phone										
n. Use your mobile phone during class or work time										
o. Watch TV shows, movies, etc. on a computer										
p. Watch video clips on a computer										
q. Download media files on a computer										
r. Share your own media files on a computer										

45) Please rate the degree to which you agree or disagree with the following statements.

	Choose from the following options				
	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
a. I feel it is important to be able to find any information whenever I want online					
b. I feel it is important to be able to access the Internet any time I want.					

c. I think it is important to keep up with the latest trends in technology.					
d. I get anxious when I don't have my cell phone.					
e. I get anxious when I don't have the Internet available to me.					
f. I am dependent on my technology.					
g. Technology will provide solutions to many of our problems.					
h. With technology, anything is possible.					
i. I feel that I get more accomplished because of technology.					
j. New technology makes people waste too much time.					
k. New technology makes life more complicated					
l. New technology makes people more isolated.					
m. My typical approach is to trust technologies until they prove to me that I shouldn't trust them.					

Privacy & Security

46) Privacy means different things to different people today. In thinking about all of your daily interactions - both online and offline - please select how important each of the following are to you

	Choose from the following options				
	Don't know	Not important at all	Not very important	Somewhat important	Very important
a. Being in control of who can get information about you					

b. Being able to share confidential matters with someone you trust					
c. Not having someone watch you or listen to you without permission					
d. Controlling what information is collected about you					
e. Not being disturbed at home					
f. Being able to have times when you are completely alone, away from anyone else					
g. Having individuals in social/work situations not ask you things that are highly personal					
h. Being able to go around in public without always being identified					
i. Not being monitored at work					
j. The ability to use the internet anonymously for certain activities					

47) Think about a typical day in your life as you spend time at home, outside your home, and getting from place to place. Consider that you might use your cellphone, landline phones or credit cards. You might go online and buy things, use search engines, watch videos, or check in on social media. How much control do you feel you have over how much information is collected about you and how it is used in your everyday life?

a. A lot of control
b. Some control

c. Not much control

d. No control at all

Driving Habits

48) Please answer the questions below

	Choose from the following options					
	Never	Hardly ever	Occasionally	Quite often	Frequently	Nearly all the time
a. How often do you try to pass another car that is signalling a left turn?						
b. How often do you select a wrong turn lane when approaching an intersection?						
c. How often do you fail to "stop" or "yield" at a sign and almost hit a car that has the right of way?						
d. How often do you misread signs and miss your exit?						
e. How often do you fail to notice pedestrians crossing when turning onto a side street?						
f. How often do you drive very close to a car in front of you as a signal that they should go						

faster or out of the way?						
g. How often do you forget where you parked your car in a parking lot?						
h. When preparing to turn from a side road onto a main road, how often do you pay too much attention to the traffic on the main road so that you nearly hit the car in front of you?						
i. How often do you hit something that you did not observe was there when backing up?						
j. How often do you pass through an intersection even though you know that the traffic light is yellow and may go red?						
k. How often have you almost hit a pedestrian or cyclist who has come up on your right side when making a turn?						
l. How often do you ignore speed limits late at night or very early in the morning?						
m. How often do you forget that your lights are on high						

beam until another driver flashes their headlights at you?						
n. How often do you fail to check your rear-view mirror before pulling out and changing lanes?						
o. How often do you have a strong dislike of a particular type of driver and indicate your dislike by any means that you can?						
p. How often do you become impatient with a slow driver in the left lane and pass on the right?						
q. How often do you underestimate the speed of an oncoming vehicle when turning left?						
r. How often do you switch on one thing (i.e., headlights) when you meant to switch on something else (i.e., windshield wipers)?						
s. How often do you brake too quickly on a slippery road or turn your steering wheel in the wrong direction while skidding?						

t. How often do you intend to drive to destination A, but "wake up" to find yourself on the road to destination B, perhaps because B is your more usual destination?						
u. How often do you drive even though you realise that you blood alcohol may be over the legal limit?						
v. How often do you get involve in spontaneous, or spur-of-the-moment races with other drivers?						
w. How often do you realise that you cannot clearly remember the road you were just driving on?						
x. How often do you get angry at the behaviour of another driver and you chase that driver so that you can give him/her a piece of your mind?						

Appendix G: Planned simulator study – VCS Tasks

No.	Prompt (and success result)	Failure result
No.	**Prompt (and success result)**	**Failure result**
Contact Tasks		
1	Send message to Jake "Running a few minutes late"	"Running a fume in its place"
2	Call Sara at work	Call Tara Atwood
3	Call Melissa Comb	Call Marissa at home
4	Send message to Mina "Remember to call Paula"	"Please remember to call plumber"
5	Call Dr. Singh	Call Dotty Zhang
6	Send message to Jim Kostas "Let's play tennis"	"Less pay tenants"
7	Call Planet Pizza	Call Pizza Pizza
8	Send message to Lana "Forgot to lock door"	Target to block floor"
9	Call Tatiana's mobile	Call Terracotta tiles
10	Send message to Brad "Leave keys in lockbox"	"Please give peace for talks"
Media Tasks		
11	Find song "I love Rock 'n' Roll" by Joan Jett	Rock and Roll by Led Zeppelin
12	Find song "Killing me softly" by Roberta Flack	Killing in the name of by Rage Against the Machine
13	Find latest episode of Planet Money	Latest episode of So Money
14	Find song "Dreams" by The Cranberries	Sweet Dreams by Eurythmics
15	Find album "The Wall" by Pink Floyd	Off the Wall Michael Jackson

16	Find song "Holland Road" by Mumford & Sons	Old Town Road by Lil Nas X
17	Find latest episode of Hidden Brain	Hit and Run
18	Find album "The Black Album" by Jay-Z	Back in Black by AC/DC
19	Find song "Money Money Money" by ABBA	Money by The Beatles
20	Find song "Frozen" by Madonna	Let it go from Frozen OST
Navigation Tasks		
21	Show directions to 2 Regal Road	Seagull Road
22	Show directions to 43 Hanna Ave	40 Diana Ave
23	Show directions to subway restaurant	Closest subway station
24	Show directions to Rachel's office	Wrench Rufus
25	Show directions to Airport	Hair Port Hair Design
26	Show directions to closest shoppers drug mart	Shoppers World Danforth
27	Show directions to Anita's house	Aunt Rita's house
28	Show directions to Yorkdale Mall	Show directions to Fork and Table
29	Show directions to closest Tim Horton's	Show directions to closest Timothy's
30	Show directions to 32 McCaul St.	Show directions to 32 Saint Paul St.

Appendix H: Planned simulator study - Experimenter protocol sheet showing example of participant VCS and task order

(Red background with red text indicates task failure)

Time	Task	Prompt
0:40	NT1	Show directions to Toronto City Hall
1:20	TT1	Message Robert "Will call when I get home"
2:00	MT1	Find album Harvest by Neil Young
2:20	MT1	Find album Harvest by Neil Young
3:00	NT2	Show directions to 156 Sheppard Ave W
3:40	TT2	Call Sheila Patel
4:00	TT2	Call Sheila Patel
4:40	MT2	Find song "From this Moment on" by Shania Twain
		Drive 1: SACDD
0:40	6	Send message to Jim Kostas "Let's play tennis"
1:20	21	Show directions to 2 Regal Road
2:00	14	14: Find song "Dreams" by The Cranberries
2:20	14	14: Find song "Dreams" by The Cranberries
2:40	14	Find song "Dreams" by The Cranberries
3:20	23	Show directions to subway restaurant
4:00	9	Call Tatiana's mobile
4:20	9	Call Tatiana's mobile
5:00	2	Call Sara at work
5:20	2	Call Sara at work
		End of Drive. Restart MiniSim software and Dlab.
		Calibrate eyetracking. Reset physiological measures if needed
		Load next scenario in MiniSim.
		Drive 2: DD1
0:40	10	Send message to Brad "Leave keys in lockbox"
1:20	22	Show directions to 43 Hanna Ave
1:40	22	Show directions to 43 Hanna Ave
2:20	13	Find latest episode of Planet Money
2:40	13	Find latest episode of Planet Money
		End of Drive. Restart MiniSim software and Dlab.

		Calibrate eyetracking. Reset physiological measures if needed
		Load next scenario in MiniSim.
		Drive 3: CDD
0:40		28: Show directions to Yorkdale Mall
1:20		19: Find song "Money Money Money" by ABBA
2:00		8: Send message to Lana "Forgot to lock door"
2:20		8: Send message to Lana "Forgot to lock door"
2:40		8: Send message to Jane "Forgot to lock door"
3:20		15: Find album "The Wall" by Pink Floyd
4:00		1: Send message to Jake "Running a few minutes late"
4:20		1: Send message to Jake "Running a few minutes late"
5:00		11: Find song "I love Rock 'n' Roll" by Joan Jett
5:20		11: Find song "I love Rock 'n' Roll" by Joan Jett
		End of Drive. Restart MiniSim software and Dlab.
		Calibrate eyetracking. Reset physiological measures if needed
		Load next scenario in MiniSim.
		Drive 4: CLD2
0:40		16: Find song "Holland Road" by Mumford & Sons
1:20		25: Show directions to Airport
2:00		26: Show directions to closest shoppers drug mart
2:20		26: Show directions to closest shoppers drug mart
2:40		26: Show directions to closest shoppers drug mart
3:20		29: Show directions to closest Tim Horton's
4:00		5: Call Dr. Singh
4:20		5: Call Dr. Singh
5:00		24: Show directions to Rachel's office
5:20		24: Show directions to Rachel's office
		End of Drive. Restart MiniSim software and Dlab.
		Calibrate eyetracking. Reset physiological measures if needed
		Load next scenario in MiniSim.
		Drive 5: DD2
0:40		7: Call Planet Pizza
1:00		7: Call Planet Pizza
1:40		30: Show directions to 32 McCaul St.

2:00		30: Show directions to 32 McCaul St.
2:40		27: Show directions to Anita's house
		End of Drive. Restart MiniSim software and Dlab.
		Calibrate eyetracking. Reset physiological measures if needed
		Load next scenario in MiniSim.
		Drive 6: CLD1
0:40		20: Find song "Frozen" by Madonna
1:20		12: Find song "Killing me softly" by Roberta Flack
2:00		18: Find album "The Black Album" by Jay-Z
2:20		18: Find album "The Black Album" by Jay-Z
2:40		18: Find album "The Black Album" by Jay-Z
3:20		4: Send message to Mina "Remember to call Paula"
4:00		3: Call Melissa Comb
4:20		3: Call Melissa Comb
5:00		17: Find latest episode of Hidden Brain
5:20		17: Find latest episode of Hidden Brain
		Done

Appendix I: Planned simulator study – Recruitment poster

Appendix J: Planned simulator study – Screening questionnaire

Online Screening Questionnaire

You are invited to participate in a research study conducted by the Human Factors and Applied Statistics Lab (Director: Prof. Birsen Donmez) at the Department of Mechanical and Industrial Engineering, University of Toronto. The experiment will take place on University of Toronto St. George campus in downtown Toronto. Participants will be compensated at a rate of $15/hour, for approximately two hours ($30 total), and has a chance to earn a performance bonus of up to $5.

The goal of this study is to understand driver behaviour and make our roads safer. If you choose to participate, you will be presented with questions about yourself and your driving behaviour. You will also be asked to perform simple tasks interacting with a voice control system while driving in a driving simulator.

Please note that all information collected will be held in the strictest confidentiality. Personal data will be stored securely in the Human Factors and Applied Statistics Lab at the University of Toronto. Under no circumstances will personal data be revealed to any third party, for any purpose. Research findings that we disseminate via scientific publications and reports will be at an aggregated level, such that no individual may be identified by any means.

At this moment, we invite right-handed drivers with a full, valid driver's license (G driver license or equivalent), normal to corrected vision, and normal hearing to complete the following questionnaire. This questionnaire will help us determine your eligibility for participating in our research. If you have any questions or concerns, please email us at hfast.vcs@gmail.com.

1. Do you understand and speak English?
    a. Yes
    b. No

2. What is your sex?
    a. Female
    b. Male
    c. Other
    d. Prefer not to answer

3. What is your age?
    a. 20-24
    b. 25-34

c. 35-44
d. 45-55

4. What valid government issued driver's license do you currently hold?
    a. Full driver's license (e.g. G license in Ontario)
    b. Learner's license (e.g. G1 and G2 licenses in Ontario)
    c. Other licenses (please specify): _________
    d. I do not currently have a valid government issued driver's license

5. How often do you drive a car or other motor vehicle?
    a. Almost every day
    b. A few days a week
    c. A few days a month
    d. A few times a year
    e. Never

6. Over the last year, how many kilometers did you drive?
    a. Under 1000
    b. Between 1,001 and 5,000
    c. Between 5,001 and 10,000
    d. Between 10,001 and 15,000
    e. Between 15,001 and 20,000
    f. Over 20,001
    g. None
    h. I don't know

7. What type of motor vehicle do you drive most often?
    a. Passenger car
    b. Pick-up truck
    c. Cargo van
    d. Box/Delivery truck
    e. Bus, tractor trailer, vehicle with more than 2 axles
    f. Other, please specify
    g. I don't know

8. What are your primary reasons for driving in a typical week (you can select multiple responses)?
    a. Commuting
    b. Business
    c. Shopping
    d. Social
    e. Recreational
    f. Other, please specify

g. I prefer not to answer

9. On a scale of 1 to 10, with 1 being very unsafe and 10 being very safe, how safe a driver do you think you are?

1	2	3	4	5	6	7	8	9	10

Very Unsafe Very Safe

10. Please provide the city and province where you drive most often:
    City:
    Province: ____________________

Some people tend to experience a type of motion sickness, called simulator sickness, when driving the simulator. The next questions are asked to help us identify if you might be prone to simulator sickness.

11. Have you ever driven in a driving simulator?
    a. No, never
    b. Once or twice
    c. Multiple times
    d. Regularly

12. If you have used a driving simulator before, did you experience simulator sickness?
    a. Yes
    b. No

13. Do you frequently experience migraine headaches?
    a. Yes
    b. No

14. Do you experience motion sickness?
    a. Yes
    b. No

15. Do you experience claustrophobia?
    a. Yes
    b. No

16. Are you pregnant?
    a. Yes
    b. No

17. How would you describe your physical well-being (over the past month including today)?
    a. Excellent
    b. Good
    c. Average
    d. Fair
    e. Poor

18. Compared with others your age, how would you rate your overall vision? (If you wear glasses or contacts, please rate your corrected.)
    a. Excellent
    b. Good
    c. Average
    d. Fair
    e. Poor

19. Compared with others your age, how would you rate your overall hearing? (If you use hearing aids, please rate your corrected hearing.)
    a. Excellent
    b. Good
    c. Average
    d. Fair
    e. Poor

In this study, we will be collecting physiological data including heart rate.

20. Are you comfortable with temporary sensors being attached to your skin (e.g., Electrocardiogram sensors)?
    a. Yes
    b. No

Thank you for filling out this questionnaire. If you're eligible for our experiment, we will contact you. Please fill in your contact information below:

21. Your first and last name:

22. Your email address:

23. Your phone number:

24. Your preferred method of contact:
    a. Email
    b. Phone
    c. Either

25. If you are interested in participating in future research at the Human Factors and Applied Statistics Lab, please indicate below:
    a. Interested
    b. Not interested

Appendix K: Planned simulator study – Consent form

Participant Consent Form

Title: Investigation of User Acceptance of In-Vehicle Voice Control Systems

Investigators: Ms. Joey Chakraborty, MASc Candidate
Tel: 408-915-5427, Email: joeych@mie.utoronto.ca

Prof. Birsen Donmez, PhD PEng | Associate Professor
Tel: 416-978-7399, Email: donmez@mie.utoronto.ca

You are being asked to take part in a research study being conducted at the Human Factors and Applied Statistic (HFASt) Lab at the University of Toronto. Before agreeing to participate in this study, it is important that you read and understand the following explanation of the proposed study procedures. The following information describes the purpose, procedures, benefits, discomforts, risks, and precautions associated with this study. In order to decide whether you wish to participate or withdraw in this research study, you should understand its risks and benefits to be able to make an informed decision. This is known as the informed consent process. Please ask the investigator to explain any words you don't understand before signing this consent form. Make sure all your questions have been answered to your satisfaction before signing this document.

Purpose
This study aims to understand driver behaviour with, and user acceptance of in-vehicle voice control systems.

Procedure
First, you will be required to complete and sign this consent form prior to the start of the experiment. Once your consent is obtained, the experimenter will ask to see your driver's license to confirm you meet the participation requirements.

After the consent is obtained, there will be three parts to this study.

1. **Introduction and Setup**
   You will fill out a questionnaire to provide your demographic information, as well as some information on your driving habits and familiarity with technology. You will be provided an introductory overview of the voice control systems (VCS) and the tasks you will be performing with them while driving in the simulator.

   We will then help you attach **physiological sensors** via adhesive electrode pads on your body and will configure the eye tracking system. The physiological sensors consist of three **electrocardiogram (ECG)** sensors on the chest, and two **galvanic skin response (GSR)** sensors on the foot. A small microphone will be attached to your person to clearly record your interactions with the voice control system.

2. **Simulated Driving**
   a. You will begin by undertaking a 5-minute **training drive** to familiarize yourself with the simulator, the driving environment, the VCS, and various events which can occur in the simulated environment. This drive will also allow you and the researcher to monitor for simulator sickness.

During the training drive, researchers will answer any questions or concerns you may have about the experimental setup or tasks.

b. You will then complete **6 experimental drives** where you will also be interacting with various VCS. The drives will last between 3 to 6 minutes, and they will be separated by 5-minute-long breaks. During the breaks you will be asked to fill out a questionnaire about your experience during the drive you just completed, including your interactions with the VCS.

We ask that you treat the simulation just like you were driving your own car, thinking of all elements of the simulation as if they were encountered in the real world. Please note that **multiple video cameras** will record your drive from various angles during this phase.

3. **Post-drive Questionnaire**
Once the drives are completed, you will be asked to fill out a final set of questionnaires concerning your driving habits and use of technology.

Risks
There are no major risks involved with this experiment. The tasks are not physiologically demanding or physiologically stressful. We want to make you aware of the **possibility of simulator sickness** (a form of motion sickness specific to simulators), however. Especially upon first using a driving simulator, there is a small chance of feeling dizzy, nauseous, or fatigued. If you experience any of these symptoms, please immediately stop the experiment and inform the investigator. The investigator will also monitor for any signs of simulator sickness.

Benefits
There are several benefits to participating in this study. The most important benefit is your contribution to research on in-vehicle technologies, which will guide the development of interfaces and other systems in automobiles. You will also gain experience with academic research and have the opportunity to use a state-of-the-art driving simulator.

Compensation
You will receive **$15/hour** for your participation plus a possible task performance bonus of up to $5. We expect the experiment to take between 2.5 to 3 hours.

Confidentiality
All information obtained during the study will be held in strict confidence. You will be identified by a study number only, and this study number will only be identifiable by the primary investigator. No names or identifying information will be used in any publication or presentation. No information identifying you will be transferred outside of this study.

Please be advised that we **video-record** the experimental trials with five small web-cameras. Two cameras will be pointed at you, one will capture the steering wheel, one the pedals, and the final camera, the overall scene. The videos will only be watched by the investigators, the primary investigator's research assistant, and research collaborators. Faces will be blurred in any video used in public presentations.

Audio recordings of your interaction with the voice control systems will also be made. In any public presentation, we will obscure your voice to maintain confidentiality.

You will be asked to fill out **several questionnaires** regarding your driving behavior, including possibly illegal activities such as speeding. Your responses to these questions will be held in strict confidentiality and no information from these questionnaires will be shared with any government or police authority.

The research study you are participating in may be reviewed for quality assurance to make sure that the required laws and guidelines are followed. If chosen, (a) representative(s) of the Human Research Ethics Program (HREP) may access study-related data and/or consent materials as part of the review. All information accessed by the HREP will be upheld to the same level of confidentiality that has been stated above.

Participation
Your participation in this study is voluntary. You can choose to not participate or withdraw at any time and still be compensated at a pro-rated basis of $15/hour for your participation to that point. Furthermore, you can also choose to skip questionnaires with no penalty.

Location
The experiment will be conducted in room 313 at Rosebrugh Building (RS), 164 College Street, Toronto, ON M5S 3E2.

Questions
You can contact the Office of Research Ethics at ethics.review@utoronto.ca, or 416-946-3273, if you have questions about your rights as a participant. If you have any general questions about this study, please call 408-915-5427 or email joeych@mie.utoronto.ca.

Consent
Please sign after reading the text in the boxes below.

Participant:

I have had the opportunity to discuss this study and my questions have been answered to my satisfaction. I consent to take part in the study with the understanding I may withdraw at any time. I have received a signed copy of this consent form. I voluntarily consent to participate in this study.

______________________	______________________	______________________
Participant's Name (please print)	Signature	Date

Investigator:

I confirm that I have explained the nature and purpose of the study to the participant named above. I have answered all questions.

______________________	______________________	______________________
Investigator's Name (please print)	Signature	Date

Appendix L: Planned simulator study – Pre-experiment questionnaire

Pre-Experiment Questionnaire

Please note that answering each question is voluntary and that you may skip questions that you are not comfortable answering.

Driving History

1. How often do you drive a car or other motor vehicle?
   a. Almost every day
   b. A few days a week
   c. A few days a month
   d. A few times a year
   e. Never

2. When did you obtain your first driver's license (knowledge test, i.e., G1 in ON, Canada or equivalent)? (MM/YYYY)

3. When did you obtain your full driver's license (G or equivalent)? (MM/YYYY)

4. What is the Year, Make and Model of the car you drive most often?

5. Do you use an in-vehicle voice control system (VCS) in this vehicle (e.g. Android Auto, Ford Sync, your smartphone, etc.)?
   a. Yes. Please indicate type:
      i. Embedded (e.g. Ford Sync)
      ii. Connected (e.g. Apple Car Play or Android Auto)
      iii. Smartphone (e.g. iPhone, Galaxy S8, Pixel, etc.)
   b. No

6. Do you normally wear corrective lenses when driving?
   a. No
   b. Yes - glasses
   c. Yes - contacts

7. Do you wear a hearing aid?
   a. No
   b. Yes

8. On a scale of 1 to 10 with 1 being very unsafe and 10 being very safe, how safe of a driver do you think you are?

1	2	3	4	5	6	7	8	9	10
Very Unsafe									Very Safe

9. In the past five years, how many times have you been stopped by a police officer and received a **warning** (but no citation or ticket) for a moving violation (i.e. speeding, running a red light, running a stop sign, failing to yield, reckless driving, etc.)?

   Enter a number: __________ (Enter 0 for none.)

10. In the past five years, how many times have you been stopped by a police officer and received a **citation or ticket** for a moving violation?

   Enter a number: __________ (Enter 0 for none.)

11. In the past five years, how many times have you been in a **vehicle crash** where you were the driver of one of the vehicles involved?

   Enter a number: __________ (Enter 0 for none.)

Technology

12. On a scale of 1 to 10, with 1 being very inexperienced and 10 being very experienced, how would you rate your level of experience with technology (e.g. cell phones, automatic teller machines, digital cameras, computers, etc.)?

1 2 3 4 5 6 7 8 9 10

Very Inexperienced Very Experienced

13. Some people prefer to avoid new technologies for as long as possible while others like to try them out as soon as they become available. In general, how would you rate yourself as being an avoider or an early adopter of new technology?

1 2 3 4 5 6 7 8 9 10

Avoid as long as possible Try as soon as possible

14. How would you rate your overall level of trust in technology?

1 2 3 4 5 6 7 8 9 10

Very Distrustful Very Trustful

15. How would you rate your level of trust in **established** car technologies (e.g. anti-lock brakes, automatic transmissions, air bags, etc.)?

1 2 3 4 5 6 7 8 9 10

Very Distrustful Very Trustful

16. How would you rate your level of trust in new technologies that are being introduced into cars?

1 2 3 4 5 6 7 8 9 10

Very Distrustful Very Trustful

17. How would you rate your ability to learn how to operate new technologies?

1	2	3	4	5	6	7	8	9	10

Very Poor Very Good

18. On mean, how often do you use an electronic navigation system in a car or truck (using a built-in navigation system, portable navigation unit or a smart phone)?
    a. More than once a day
    b. About once a day
    c. A few times a week
    d. A few times a month
    e. A few times a year
    f. Never

19. How often do you use a voice command interface in **any environment** (on a smart phone, in your car, or some other voice enabled system such as speech to text translation software)?
    a. More than once a day
    b. About once a day
    c. A few times a week
    d. A few times a month
    e. A few times a year
    f. Never

20. How often do you use voice command interface systems **in vehicles**?
    a. More than once a day
    b. About once a day
    c. A few times a week
    d. A few times a month
    e. A few times a year
    f. Tried it a few times and haven't used it since
    g. Never

Demographics

The following are standard questions that allow researchers to determine how representative the group of participants in a study is of the general population. Remember, filling out this questionnaire is voluntary. Skipping any question that makes you feel uncomfortable will not exclude you from the study.

21. Please describe the highest level of formal education you have completed:
    a. Some high school or less
    b. High school graduate
    c. Some college
    d. College graduate
    e. Some graduate education
    f. Completed graduate or professional degree (e.g. Masters, LCSW, JD, Ph.D., MD, etc.)

22. Are you (please select all that apply):
    a. A full-time student
    b. A part-time student
    c. Unemployed
    d. Retired
    e. Employed full-time
    f. Employed part-time
    g. A full-time caregiver (e.g. children or elder)
    h. A part-time caregiver (e.g. children or elder)
    i. None of the above

23. Are you:
    a. Married
    b. Divorced
    c. Widowed
    d. Single living with partner

e. Single never married

f. Prefer not to answer

24. What best describes your total household income?
    a. Less than $25,000
    b. $25,000 – $49,999
    c. $50,000 – $74,999
    d. $75,000 – $99,999
    e. $100,000 – $124,999
    f. $125,000 – $149,999
    g. $150,000 or more
    h. I don’t know

Appendix M: Planned simulator study – Post-drive questionnaires

Questionnaire 1

Please describe the voice control system **you just used**:

	Strongly	Somewhat	Neutral	Somewhat	Strongly	
Useful	○	○	○	○	○	Useless
Pleasant	○	○	○	○	○	Unpleasant
Bad	○	○	○	○	○	Good
Nice	○	○	○	○	○	Annoying
Effective	○	○	○	○	○	Superfluous
Irritating	○	○	○	○	○	Likeable
Assisting	○	○	○	○	○	Worthless
Undesirable	○	○	○	○	○	Desirable
Raising Alertness	○	○	○	○	○	Sleep-Inducing

Questionnaire 2

Please mark an 'x' on each line at the point which best describes your feelings or your impression about the system **you just used**:

(Note: not at all=1; extremely=7)

1 The system is deceptive

1 2 3 4 5 6 7

2 The system behaves in an underhanded manner

1 2 3 4 5 6 7

3 I am suspicious of the system's intent, action, or outputs

1 2 3 4 5 6 7

4 I am wary of the system

1 2 3 4 5 6 7

5 The system's actions will have a harmful or injurious outcome

1 2 3 4 5 6 7

6 I am confident in the system

1 2 3 4 5 6 7

7 The system provides security

1 2 3 4 5 6 7

8 The system has integrity

1 2 3 4 5 6 7

9 The system is dependable

1 2 3 4 5 6 7

10 The system is reliable

1 2 3 4 5 6 7

11 I can trust the system

1 2 3 4 5 6 7

12 I am familiar with the system

1 2 3 4 5 6 7

Questionnaire 3

The scenario **you just drove** was **as risky as**:

( ) 10: driving with my eyes closed; A crash is bound to occur every time I do this

( ) 9: passing a school bus that has its red lights flashing and the stop arm in full view

( ) 8: driving just under the legal alcohol limit with observed weaving in the lane

( ) 7: in between 6 & 8

( ) 6: driving 20 miles per hour faster than traffic on an expressway

( ) 5: in between 4 & 6

( ) 4: driving 10 miles an hour faster than traffic on an expressway

( ) 3: in between 2 & 4

( ) 2: driving on an average road under average conditions

( ) 1: driving on an easy road with no traffic, pedestrians, or animals while perfectly alert

Questionnaire 4

The purpose of this questionnaire is to assess your subjective workload while you drive the last driving scenario. The subscales used to rate workload include mental demand, physical demand, temporal demand, own performance, effort, and frustration.

Please consider the workload of the task **as a whole**, i.e., driving AND using the VCS, for each question.

Part 1: Scaling

1) Mental Demand - How much mental or perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching etc.?); Was the task easy or demanding, simple or complex?

Question: How mentally demanding was the task?

Very Low   Very High

1 __________________________[__]________________________________ 20

2) Physical Demand - How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating etc.?)

Question: How physically demanding was the task?

Very Low   Very High

1 __________________________[__]________________________________ 20

3) Temporal Demand - How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

Question: How hurried or rushed was the pace of the task?

Very Low   Very High

1 __________________________[__]________________________________ 20

4) Performance - How stressful do you think you were in accomplishing the goals of the task? How satisfied were you with your performance in accomplishing these goals?

Question: How successful were you in accomplishing what you were asked to do?

(*Please note:* The scale is from PERFECT to FAILURE going left to right)

Perfect Failure

1 _________________________[__]______________________________ 20

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

Question: How hard did you have to work to accomplish your level of performance?

Very Low Very High

1 _________________________[__]______________________________ 20

6) Frustration Level - How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Question: How insecure, discouraged, irritated, stressed and annoyed were you?

Very Low Very High

1 _________________________[__]______________________________ 20

Part 2: Pair Comparison

Please examine the following pairs of subscales. For each pair, put an ‘x’ next to the element that you feel contributed to the workload more when you did the last drive.

7) ( ) Mental Demand ( ) Physical Demand

8) ( ) Mental Demand ( ) Temporal Demand

9) ( ) Mental Demand ( ) Performance

10) ( ) Mental Demand ( ) Effort

11) ( ) Mental Demand ( ) Frustration

12) ( ) Physical Demand ( ) Temporal Demand

13) ( ) Physical Demand ( ) Performance

14) ( ) Physical Demand ( ) Effort

15) ( ) Physical Demand ( ) Frustration

16) ( ) Temporal Demand ( ) Performance

17) ( ) Temporal Demand ( ) Effort

18) ( ) Temporal Demand ( ) Frustration

19) ( ) Performance ( ) Effort

20) ( ) Performance ( ) Frustration

21) ( ) Effort ( ) Frustration

Appendix N: Planned simulator study – Post-experiment questionnaires

Questionnaire 1

For the following questions, indicate to what extent you agree or disagree with each statement.

Section 1

While driving, to what extent would you have difficulty ignoring	Not at all	Small extent	Moderate extent	Large extent	Extremely large extent
the ringing of a cell phone (e.g., incoming call), which you do not intend to answer					
conversation amongst passengers in the backseat					
a fly that got into your vehicle					
roadside advertisements					
loud music from another vehicle					
an alert from your cell phone about an update on social media					
an alert from your cell phone of a new message, or an incoming call (excluding social media)					
a roadside accident scene					
an itch on your back					

While driving, to what extent do you feel compelled to	Not at all	Small extent	Moderate extent	Large extent	Extremely large extent
check your phone when you receive a notification from social media					
check your phone when you receive a notification of a new message					

check your phone when you receive a notification of an incoming call					
read an advertisement fully once you see it					

How often do you…	Never	Rarely	Occasionally	Often	Very often
find yourself having looked away from the road for longer than you intended to?					
find yourself being surprised by what you see on the road, after having looked away from the road?					
look away from the road and are surprised by how fast/slow you are going when you glance back at the speedometer?					
find yourself having drifted out of your lane because you looked away from the road?					
turn off your cell phone/tablet before driving to reduce distractions while driving?					

Section 2

Checking my phone for new notifications is something…	Strongly disagree	Disagree	Undecided	Agree	Strongly agree
I do automatically					
I do without having to consciously remember					
I do without thinking					
I start doing before I realize I am doing it					
I have no need to think about doing					

I do without meaning to do it					
That would require effort not to do it					
That I would find hard not to do					
That is typically ‘me’					
That belongs to my daily routine					

Answering a phone call is something…	Strongly disagree	Disagree	Undecided	Agree	Strongly agree
I do automatically					
I do without having to consciously remember					
I do without thinking					
I start doing before I realize I am doing it					
I have no need to think about doing					
I do without meaning to do it					
That would require effort not to do it					
That I would find hard not to do					
That is typically ‘me’					
That belongs to my daily routine					

Responding to notifications on my cell phone is something…	Strongly disagree	Disagree	Undecided	Agree	Strongly agree
I do automatically					
I do without having to consciously remember					
I do without thinking					
I start doing before I realize I am doing it					

I have no need to think about doing					
I do without meaning to do it					
That would require effort not to do it					
That I would find hard not to do					
That is typically 'me'					
That belongs to my daily routine					

Checking my navigational system (e.g., GPS) to verify if I am on route is something…	Strongly disagree	Disagree	Undecided	Agree	Strongly agree
I do automatically					
I do without having to consciously remember					
I do without thinking					
I start doing before I realize I am doing it					
I have no need to think about doing					
I do without meaning to do it					
That would require effort not to do it					
That I would find hard not to do					
That is typically 'me'					
That belongs to my daily routine					

Questionnaire 2

Please answer the following questions	Never	Rarely	Sometimes	Often	Very Often
Do you read something and find you haven't been thinking about it and must read it again?					
Do you find you forget why you went from one part of the house to the other?					
Do you fail to notice signposts on the road?					
Do you find you confuse right and left when giving directions?					
Do you have trouble making up your mind?					
Do you daydream when you ought to be listening to something?					
Do you start doing one thing at home and get distracted into doing something else (unintentionally)?					
Do you find you can't quite remember something although it's 'on the tip of your tongue'.					

Questionnaire 3

Nobody is perfect. Even the best drivers make mistakes, do foolish things, or bend the rules at some time or another. For each item below you are asked to indicate HOW OFTEN, if at all, this kind of thing has happened to you. Base your judgments on what you remember of your driving. Please indicate your judgments by placing a check mark next to each item. We do not expect exact answers, merely your best guess; so please do not spend too much time on any one item.

How often do you do each of the following	Never	Hardly ever	Occasionally	Quite Often	Frequently	Nearly all the time
a. Try to pass another car that is signaling a left turn.						
b. Select a wrong turn lane when approaching an intersection.						
c. Failed to “stop” or “yield” at a sign, almost hit a car that has the right of way.						
d. Misread signs and miss your exit.						
e. Fail to notice pedestrians crossing when turning onto a side street.						
f. Drive very close to a car in front of you as a signal that they should go faster or get out of the way.						
g. Forget where you parked your car in a parking lot.						
h. When preparing to turn from a side road onto a main road, you pay too much attention to the traffic on the main road so						

that you nearly hit the car in front of you.						
i. When you back up, you hit something that you did not observe before but was there.						
j. Pass through an intersection even though you know that the traffic light has turned yellow and may go red.						
k. When making a turn, you almost hit a cyclist or pedestrian who has come up on your right side.						
l. Ignore speed limits late at night or very early in the morning.						
m. Forget that your lights are on high beam until another driver flashes his headlights at you.						
n. Fail to check your rear-view mirror before pulling out and changing lanes.						
o. Have a strong dislike of a particular type of driver and indicate your dislike by any means that you can.						
p. Become impatient with a slow driver in the left lane and pass on the right.						
q. Underestimate the speed of an oncoming vehicle when passing.						

r. Switch on one thing, for example, the headlights, when you meant to switch on something else, for example, the windshield wipers.						
s. Brake too quickly on a slippery road or turn your steering wheel in the wrong direction while skidding.						
t. You intend to drive to destination A, but you 'wake up' to find yourself on the road to destination B, perhaps because B is your more usual destination.						
u. Drive even though you realize that your blood alcohol may be over the legal limit.						
v. Get involved in spontaneous, or spur-of-the moment, races with other drivers.						
w. Realize that you cannot clearly remember the road you were just driving on.						
x. You get angry at the behavior of another driver and you chase that driver so that you can give him/her a piece of your mind.						

Questionnaire 4

1) How would you rate the overall level of trust in a traditional automaker (e.g., Ford, Toyota, GM, etc.) to produce reliable technology?

( ) -5 ( ) -4 ( ) -3 ( ) -2 ( ) -1 ( ) 0 ( ) 1 ( ) 2 ( ) 3 ( ) 4 ( ) 5

Very Distrustful Very Trustful

2) How would you rate your overall level of trust in a Silicon Valley tech company (e.g., Apple, Google, etc.) to produce reliable technology?

( ) -5 ( ) -4 ( ) -3 ( ) -2 ( ) -1 ( ) 0 ( ) 1 ( ) 2 ( ) 3 ( ) 4 ( ) 5

Very Distrustful Very Trustful

3) How do you feel about the technology in the car you drive today? Select the closest answer.

a. I'm very unhappy with the technology
b. I like some features, but don't use most
c. I have no opinion
d. I like most of the features
e. I'm very happy with the technology

4) For your most recent car purchase, do you feel that the sales staff encouraged you to buy technology that was not needed?

a. Yes
b. No
c. Don't know or unsure

5) How did you learn to use the technology in the car you drive today? Select all that apply.

a. A friend or family member
b. Websites or on-line videos
c. Dealer while interacting with sales staff
d. Dealer during delivery
e. Vehicle manual
f. Other material provided by the manufacture
g. Trial and error
h. By luck
i. I don't know how to use the technology in my car
j. Other (please specify)

6) How would you prefer to learn about the technology in the car you drive today? Select all that apply.

a. A friend or family member
b. Websites or on-line videos
c. Dealer while interacting with sales staff
d. Dealer during delivery
e. Vehicle manual
f. Other material provided by the manufacture
g. Trial and error
h. By luck
i. The car teaches me
j. Other (please specify)

7) Are you happy with how that technology is integrated with the design of your car today?

( ) -5 ( ) -4 ( ) -3 ( ) -2 ( ) -1 ( ) 0 ( ) 1 ( ) 2 ( ) 3 ( ) 4 ( ) 5

Very Unhappy Very Happy

Questionnaire 5

1) How did you learn to use the technology you use today? Select all that apply.

a. A friend and/or family member
b. Websites and/or online videos
c. Trial and error
d. By luck
e. Other - Please specify:
f. I don't know how to use the technology
a. A friend and/or family member
b. Websites and/or online videos
c. Trial and error
d. By luck
e. The technology teaches me
f. Other - Please specify:

3) How often do you do each of the following?

	Choose from the following options									
	Never	Once a month	Several times a month	Once a week	Several times a week	Once a day	Several times a day	Once an hour	Several times an hour	All the time
Send, receive, and read e-mails (not including spam or junk mail)										
Check your personal email										
Check your work/school email										
Send/receive files via email										
Send/receive text messages										

on your mobile phone										
Make/receive phone calls on your mobile phone										
Read email on your mobile phone										
Get directions or use GPS on your mobile phone										
Browse the internet on your mobile phone										
Listen to music/podcasts on your mobile phone										
Take pictures/record video on your mobile phone										
Use apps (for any purpose) on your mobile phone										
Search for information on your mobile phone										
Use your mobile phone during class or work time										
Watch TV shows, movies, etc. on a computer										

Watch video clips on a computer										
Download media files on a computer										
Share your own media files on a computer										

4) Please rate the degree to which you agree or disagree with the following statements.

	Choose from the following options				
	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
I feel it is important to be able to find any information whenever I want online					
I feel it is important to be able to access the Internet any time I want.					
I think it is important to keep up with the latest trends in technology.					
I get anxious when I don't have my cell phone.					
I get anxious when I don't have the Internet available to me.					
I am dependent on my technology.					
Technology will provide solutions to many of our problems.					
With technology, anything is possible.					
I feel that I get more accomplished because of technology.					
New technology makes people waste too much time.					
New technology makes life more complicated					

New technology makes people more isolated.					
My typical approach is to trust technologies until they prove to me that I shouldn't trust them.					