Driving under Involuntary and Voluntary Distraction: Individual Differences and Effects on Driving Performance

by

Liberty Hoekstra-Atwood

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

Driving under Involuntary and Voluntary Distraction: Individual Differences and Effects on Driving Performance

Liberty Hoekstra-Atwood

Master of Applied Science

Mechanical and Industrial Engineering
University of Toronto

2015

Abstract

Distracted driving compromises safety. Distractions stem from intentional engagement in secondary tasks (voluntary) or an inability to supress non-driving related information (involuntary). This thesis aims to understand, through two driving simulator experiments, how involuntary and voluntary distraction affect drivers and individual differences in susceptibility to either type of distraction. Findings show involuntary and voluntary distraction degrade driving performance. Drivers appear more cognisant of voluntary distractions compared to involuntary distraction. They compensate for their accelerator release delays in response to lead vehicle braking by transitioning more quickly to the brake pedal under voluntary distraction, but not under involuntary distraction. Drivers self-reporting frequent distraction engagement in real-world driving glanced more frequently at the voluntary distraction task used in the experiments and drivers self-reporting greater everyday distractibility had longer glances toward involuntary distraction stimuli. Involuntary distraction engagement was not related to the manipulated environmental visual complexity nor inhibition ability measured through cognitive tasks.

Acknowledgments

First and foremost, I would like to thank my supervisor Professor Birsen Donmez. She has diligently guided me throughout the research process, taken the time to thoroughly review this thesis, given me valuable advice on how to conduct driving research, and provided opportunities to network with researchers in the driving research community.

I would like to express my thanks to my committee members, Professor Paul Milgram and Professor Greg Jamieson for their insights and their engaging questions during my defense. Their detailed feedback has improved the quality of this thesis.

I would like to recognize the contributions of Jim Foley and Kazu Ebe, our Toyota Collaborative Safety Research Center (CSRC) collaborators, for their feedback and insights on this body of work. I would like to acknowledge the CSRC and Auto 21 Network of Centers of Excellence who provided the funding for this research.

I am extremely grateful to my co-collaborators, Dr. Winnie Chen and Susana Marulanda whose friendship made this research so much fun. I will always appreciate the guidance Winnie provided with my statistical analysis and her advice on how to navigate through the academic world. I will always fondly remember the late nights Susana and I spent bouncing ideas off each other about our experimental design, running experiments, and writing R code.

I would like to thank the other members of the HFASt lab who donated their time to read my papers, listen to my presentations, and offer feedback on my research. These very important people include Wayne Giang, Maryam Merrikhpour, Farzan Sasangohar, Patrick Stahl, Jeanne Xie, and Pamela D’Addario.

I am eternally grateful for my parents, Jelke Hoekstra and Serena Atwood, and my brother Arend Hoekstra for their non-stop support, love, prayers, and entertaining phone calls, even in the most stressful times.

I would like to thank Michael for always having my back. Thanks also goes out to the Small Council (Stephanie, Kevin, Jacob, and Kit) for joining me on after-work adventures and regularly being open to brunch.

Table of Contents

List of Tables

List of Figures

List of Appendices

Chapter 1

1.0 Introduction

1.1 Motivation

Distracted driving compromises the safety of all road users. Driver distraction has been defined as the diversion of attention away from activities critical for safe driving toward a competing activity (Foley, Young, Angell, & Domeyer, 2013; Lee, Young, & Regan, 2008). Distraction has been described as having five aspects: source, location of source, intentionality, process, and outcome (Lee et al., 2008). In the current work, distraction is divided within the elements of intentionality to differentiate between distraction behaviours and outcomes that stem from intentional engagement in secondary tasks (voluntary distraction) and inability to suppress non-driving related information or stimuli (involuntary distraction). An example of voluntary distraction is choosing to make a phone call while driving and an example of involuntary distraction is when driver attention is diverted involuntarily by competing activities such as overhearing passenger conversations. An Australian national crash study found that of all distractions that contributed to crashes, 70% were voluntary; the remaining were identified as involuntary distractions (Beanland, Fitzharris, Young, & Lenné, 2013). Although involuntary distraction has been the subject of prior research in other fields (e.g., Forster & Lavie, 2008; Lavie, 2005), the existing research in the driving domain has been very limited, mostly to roadside advertisements (e.g., Bendak & Al-Saleh, 2010; Chattington, Reed, Basacik, Flint, & Parkes, 2009; M. Young & Mahfoud, 2008). Further, driver distraction is generally studied through tasks imposed on the driver and there is a need to further investigate intentional distraction engagement by allowing participants to self-regulate the initiation and pace of secondary tasks. This thesis aims to help address these gaps.

This thesis is also timely, as in-vehicle displays are becoming a greater part of the driving console: the Tesla Model S infotainment display is a 17 inch capacitive touchscreen (Tesla Motors, 2015). In addition, influential companies are exploring the possibility of moving advertising into the car, for example, in a filing for the U.S. Securities and Exchange Commission (Google Inc, 2013), Google Inc. indicated they would be exploring serving ads and other content on car dashboards: “We expect the definition of ‘mobile’ to continue to evolve as more and more ‘smart’ devices gain traction in the market. For example, a few years from now, we and other companies could be serving ads and other content on refrigerators, car dashboards, thermostats, glasses, and watches, to name just a few possibilities.” The design of these in-car advertisements may affect drivers’ ability to attend to the driving task. At the 2015 Consumer Electronics Show, General Motors presented a new ‘commerce and engagement offering’ that it will be rolling out to 30 automobile models with 4G-LTE connectivity in 2015. This service includes functionality that alerts drivers, who are subscribers, to products and service deals near their destination whilst they are driving (White & Fowle, 2015). It is therefore important that driving under involuntary distraction be assessed to identify how salient stimuli that are irrelevant to the driving task may affect driving behaviour, and what characteristics make a driver more or less susceptible to this type of distraction.

Overall, to design better mitigation strategies, it is important to understand the underlying causes of different types of distraction and their effects on drivers, especially on those more prone to driver distraction. A better understanding of these causes and effects should facilitate designing systems that impose limited load on drivers’ attentional resources, and encourage long term improvements in driving performance and behaviour. The **objectives of this research** are to understand how involuntary and voluntary distraction may affect drivers differently, to examine whether individual differences in driver characteristics and cognition relate to drivers’ susceptibility to either type of distraction, and to investigate if involuntary distractions may be more or less distracting under different driving environments.

1.2 Research questions and scope

This research investigates the causes and effects of distractions by making a distinction between distraction behaviours and outcomes that stem from intentional engagement in secondary tasks (voluntary distraction) and inability to suppress non-driving related information or stimuli (involuntary distraction). This distinction and in particular involuntary distractions remain relatively unstudied despite the well-documented evidence of detrimental effects of involuntary and voluntary distractions on driver performance (McEvoy et al., 2007; Beanland, Fitzharris, Young, & Lenné, 2013; see K. Young, Regan, & Hammer, 2007 for a review). Two driving simulator experiments were conducted to help address this gap.

The goal of Experiment 1 was to investigate the effects of involuntary and voluntary distraction on simulated driving behaviour and to examine how individual differences, assessed through self-reported measures, affect distraction engagement in the simulator. Thirty-six participants were observed under three distraction conditions: driving while performing a self-paced secondary-task on a secondary display that is irrelevant to the driving task (voluntary distraction), driving while unexpected, driving-irrelevant stimuli appeared on the secondary display (involuntary distraction), and a baseline condition with no distractions. The participants also filled out the Susceptibility to Driver Distraction Questionnaire (SDDQ) (Feng, Marulanda, & Donmez, 2014) which collected data on self-reported frequency of distraction engagement. Previous work on SDDQ has shown that self-reported frequency of distraction engagement is related to attitudes, perceived behavioural control, and social norms related to voluntary distraction engagement (Feng et al., 2014). Although the relationships between self-reported voluntary distraction engagement and voluntary distraction facilitators have been identified, self-reported engagement frequency with voluntary distractions has not been validated through observations of distraction engagement during the driving task. Therefore, Experiment 1 aimed to further validate these relationships by evaluating self-reported frequency of distraction, measured by SDDQ, against measures of observed voluntary distraction behaviour. SDDQ involuntary distraction attributes were also evaluated using measures of observed involuntary distraction behaviour. In addition, contrasts were drawn between the effects of voluntary and involuntary distractions on driving performance.

Experiment 2 examined simulated driving performance under involuntary distraction, including the modulating effects of environmental visual complexity (i.e., urban and rural environments). Perception research posits that in tasks with low perceptual load, spare perceptual capacity not used by task-relevant stimuli involuntarily “spills over” and is used to perceive task-irrelevant distractors (Forster & Lavie, 2008). However, when a task requires high perceptual load, distractor processing is prevented because perceptual load capacity is exhausted. Thus, drivers may be better at inhibiting irrelevant stimuli (i.e., involuntary distraction) when driving under high perceptual load. To test this hypothesis, an additional 24 participants were observed in Experiment 2 under two distraction conditions (involuntary distraction and baseline) and two visual perceptual loads (an urban road imposing higher perceptual load and a rural road imposing lower perceptual load). Experiment 2 also evaluated self-reported and cognitive measures against measures of involuntary distraction in simulated driving. These self-reported and cognitive measures include self-reported measures of involuntary distraction from a revised version of SDDQ (Marulanda, Chen, & Donmez, 2015b), Everyday Distractibility questions from the

Cognitive Failures Questionnaire (Broadbent et al., 1982), and individual differences in inhibitory control from well-established measures of cognitive ability: flanker (Eriksen & Eriksen, 1974) and Stroop tasks (Stroop, 1935).

1.3 Thesis overview

- Chapter 2 provides an introduction to relevant driving distraction literature, including how individual differences in attitudes, beliefs, personality and demographics affect susceptibility to voluntary distraction and how environmental factors and individual differences in cognition may influence susceptibility to involuntary distraction.
- Chapter 3 presents Experiment 1: a driving simulator study assessing the effects of voluntary and involuntary distraction on driving performance as well as the relationship between distraction behaviours observed in the simulator and self-reported distraction engagement.
- Chapter 4 presents Experiment 2: a driving simulator study assessing the effects of involuntary distraction on driving performance and investigating the relationship between involuntary distraction engagement (self-reported and in simulated driving), individual differences in cognition, and driving environment.
- Chapter 5 discusses the implications of the results from Experiments 1 and 2.
- Chapter 6 provides a summary of the research contributions to the driver distraction domain and recommendations for future work.

Chapter 2

2.0 Literature Review

2.1 Voluntary and involuntary driver distraction

2.1.1 Definitions

As stated previously, a driver is said to be engaged in distraction when his or her attention is diverted “away from activities critical for safe driving towards a competing activity” (Foley et al., 2013; Lee et al., 2008). Distraction has been described as having five aspects: source, location of source, intentionality, process, and outcome (Lee et al., 2008). The current work focuses on the intentionality aspect of driver distraction. A driver may be compelled to attend to an external distraction source, and thus engage with it unintentionally (involuntary distraction), or it is the driver’s intention to engage with the distraction (a voluntary distraction).

This distinction can be further understood through a framework of attention selection in driving proposed by Trick and Enns (2009). Unlike Lee et al.’s five elements of distraction (2008), this framework focuses on attention selection and allows for exploring the intentionality aspect of distraction in more depth. The framework describes four modes of attention selection that vary along two separate dimensions: the selection process (which is analogous to intentionality) and the origin of the selection process. The selection process ranges between automatic (selection without awareness) and controlled selection. The origin of the selection process ranges from bottom-up (exogenous) selection, where the origin exists as a result of the innate preferential treatment of different stimuli by the human nervous system due to stimuli salience, to top-down (endogenous) selection where the origin is motivated by expectations or driver goals (Engstrom, Victor, & Markkula, 2013; Trick & Enns, 2009).

Although Trick and Enns’s (2009) attention selection framework varies along two continuous dimensions, their four modes of attention selection are categorized based on the ends of these continuums. These dichotomous modes are reflex (automatic, stimulus driven), exploration (automatic, goal driven), habit (controlled, stimulus driven), and deliberation (controlled, goal driven) (Figure 1). In this thesis, voluntary and involuntary distraction are also treated dichotomously, although it should be acknowledged that each distraction scenario may vary in its position along these continuum. Similar distraction tasks may not use the exact same amount of intentionality, e.g., the selection process for engaging with a phone may be more controlled when a driver intends to check a phone for entertainment and more automatic when a driver compulsively checks a phone for notifications. In addition, there are distractions that may not be clearly categorized, e.g., a driver may be triggered both endogenously and exogenously to eat a burger while driving because they want to reduce their hunger and at the same time perceived the smell of the burger. A distraction source's type may also change over time. For example, deciding to pick up a phone (distraction source) to dial is voluntary, but if the phone slips and falls, the reflexive response to try to catch the phone is involuntary (Regan, Hallett, & Gordon, 2011).

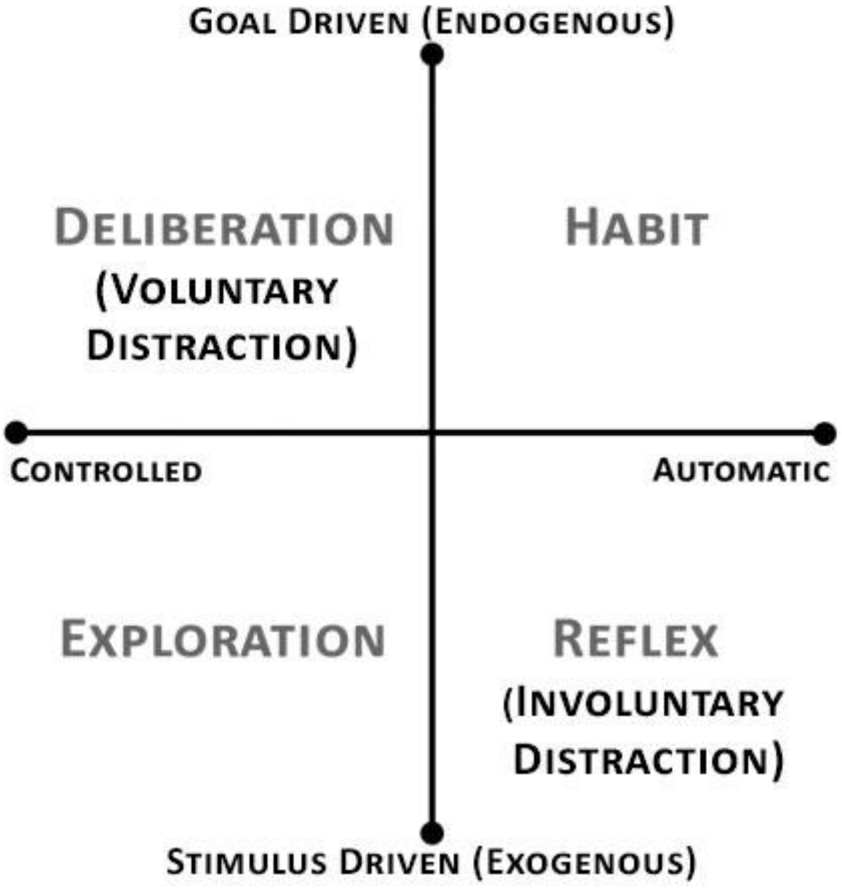


Figure 1: The mapping of voluntary and involuntary distraction within the attention selection modes depicted as described by Trick and Enns (2009)

To summarize, the current work maps voluntary and involuntary distraction to Trick and Enns' framework (2009) as follows:

1. Voluntary distraction falls into the deliberation attention selection quadrant (Figure 1) since it is a goal driven process to intentionally engage in secondary tasks while driving (e.g., sending text messages or talking on the phone). Because voluntary distraction uses deliberate attention selection, it is likely to interfere with other deliberate attention selection driving activities such as checking for cyclists (Engstrom et al., 2013).
2. Involuntary distraction falls in the reflex attention selection quadrant (Figure 1), as it is an automatic, stimulus driven process of attending to irrelevant stimuli or information during the driving task (e.g., diverting attention to a ringing phone or passenger conversation while driving). A reflexive attention selection process may be interfered through visual disruption such as blinking or obstructions in the visual field, such as a bush or a post blocking a driver's view of the roadway. The ability of stimuli to attract bottom-up attention may be affected by concurrent top-down attention selection: if a task requiring deliberate attention selection loads perceptual capacity, the bottom-up attention capture power of task-irrelevant stimuli is reduced (Lavie, 2005).
3. There are distractions that are driven by both exploration and habitual attention selection modes and thus do not fit in the voluntary and involuntary distraction dichotomy. These are not addressed in this thesis.

2.1.2 Road safety

Driver distraction is a cause of traffic crashes. In 2011, driver distraction was listed as a causal factor in 10% of all fatal U.S. crashes (3,020) and in 17% of crash injuries (387,000 people) (National Highway Traffic Safety, 2013). With respect to the breakdown of how many distraction-contributed crashes are due to voluntary versus involuntary distraction, a national Australian crash study classified 70% of all the distractions found contributing to crashes as voluntary distractions and identified the remaining 30% as involuntary distractions (Beanland et al., 2013).

Drivers' attention is frequently captured by items irrelevant to the driving task, such as scenery or roadside advertisements. The amount of time that drivers' visual attention is focused on objects irrelevant to the driving task varies depending on spare attention capacity (Hughes & Cole, 1986), and comprises a large portion of driving time. Hughes and Cole (1986) observed two groups of drivers continuously describing everything they glanced toward. The first group performed this task while driving on the road and the second group performed this task while watching a video of an on-road driving route from a driver’s perspective. They observed that drivers spent 30-50% of their driving time attending to irrelevant objects. In addition, Green (2002) further analysed data from an on-road study conducted by Mourant, Rockwell, and Rackoff (1969), where drivers’ fixations were recorded using an electronic eye fixation recording system. Green (2002) identified 20% of all fixations during the experimental drives to be towards objects irrelevant to driving. Although it is not unusual for drivers to fixate on irrelevant stimuli while driving, these involuntary distractions may become problematic when they capture attention at the wrong time, or if drivers cannot disengage from the stimulus in a timely manner: several studies have demonstrated that humans cannot ignore sudden and unexpected stimuli (e.g., visual, tactile, auditory) regardless of their irrelevance to the primary task (Bella, 2013; Landry, Sheridan, & Yufik, 2001; McEvoy, Stevenson, & Woodward, 2007; Yantis & Jonides, 1990). For example, an Australian study collected self-reported crash data on 1,367 drivers hospitalized following a car crash. Of these drivers, 11% attributed the recent crash to apparent non-driving related factors: 5.1% to distraction from outside persons, objects, or events; 4.4% to lack of concentration; and 1.5% to distraction from other objects, animals, or insects in the vehicle (McEvoy et al., 2007). In addition, increased rates of car crashes have been associated with road sections which have a greater number of roadside billboards: see Wallace (2003) for review.

2.2 Previous research on driving while performing secondary tasks

Driver distraction is often studied through tasks where the task initiation time or task engagement amount are imposed on the driver (Caird & Horrey, 2011; Horrey & Lesch, 2008). Although there are some examples of driver distraction studies using self-paced tasks, these are rarely self-initiated in a controlled setting. Naturalistic driving studies can capture crash risk increases due to self-initiated and self-paced secondary task engagement, but to understand how driving performance is degraded under distraction and how individual differences may affect the level of degradation, there is a need to further investigate intentional distraction engagement through controlled experiments by allowing participants **to self-regulate both the initiation and the pace of secondary tasks**, as they would in real-world driving.

The majority of distracted driving studies do not use self-paced secondary tasks. Of 37 driving simulation studies available online and reviewed in two meta-analysis papers on driver distraction from cellphone use (conversing and texting) (Caird, Johnston, Willness, Asbridge, &

Steel, 2014; Caird, Willness, Steel, & Scialfa, 2008), all 37 studies used task paradigms that were not self-paced or where the task initiation was not self-regulated. More specifically, the secondary tasks fell into three categories. (1) Continuously cued tasks: participants were prompted to initiate a task and expected to engage in the task, such as conversing with the experimenter, until the drive was completed. Continuously cued tasks were used in 8 cellphone conversation papers and 6 texting papers. (2) Discrete cued tasks: participants were given cues to start a task at pre-planned locations or time intervals during the experiments and had to respond as quickly and accurately as possible. Discrete cued tasks were utilized in 6 cellphone conversation papers and 15 texting papers. (3) Quota tasks: tasks were self-paced but participants needed to perform a pre-determined number of tasks. Quota tasks were mentioned in 2 papers: one cellphone conversation study had a set number of questions that participants were required to answer, but participants were allowed to answer when they felt able to do so (Parkes & Hooijmeijer, 2001) and one texting study had a food eating condition that was self-paced, but participants in that group were expected to eat all the food items provided within the span of the drive (Alosco et al., 2012). The studies reviewed in Caird et al.'s (2014) meta-analysis on texting showed that typing and reading text messages concurrently with driving had a negative impact on reaction time, eye movements, stimulus detection, collisions, lane positioning, speed and headway. Performance decrements in the same metrics were observed while solely reading text messages, although with smaller effect sizes. The meta-analysis on cellphone conversation studies found that drivers' had delayed reaction times to events and stimuli while talking on a phone, and that these performance decrements were similar between hand-held and hands-free phones (Caird et al., 2008).

In contrast to Caird et al.'s findings (2008), naturalistic driving studies, where secondary tasks are naturally self-paced, have found evidence that talking and listening on a cellphone while driving does not increase the risk of safety-critical events, and can sometimes create a protective effect. The lack of increased risk due to talking and listening on a cellphone in naturalistic driving has been attributed to drivers' gaze being on the road (Fitch, Grove, Hanowski, & Perez, 2014; Victor et al., 2015), which may increase the likelihood that drivers will prevent rear-end collisions (Victor et al., 2015). In addition, the protective effect may also be due to drivers decreasing the frequency of their lane changes, as was observed for commercial vehicle drivers (Fitch et al., 2014).

Although less common, self-paced secondary tasks have been used in controlled studies, and have been shown to degrade driving performance differently than secondary tasks controlled by the experimenter. For example, in a laboratory study, experimenters used an apparatus designed to simulate the foot activity in an vehicle with automatic transmission to test braking performance under a controlled conversation task (i.e., individuals responding to scripted conversation questions continuously), brake reaction times were delayed similarly regardless of whether conversations were conducted in-person (with a ‘passenger’), via a hand-held cellphone, or via a hands-free cellphone (Consiglio, Driscoll, Witte, & Berg, 2003). In contrast, in a simulated driving study using self-paced conversation (although not self-initiated), when drivers conversed with a passenger who was physically present in the car, they exhibited reaction time delays and shortened time to collision, but they exhibited even longer delays and shorter time to collision when conversing on a cellphone or with a remote passenger (who was not in the car, but was aware of the drivers’ situation) (Charlton, 2009).

Metz, Schömig, & Krüger (2011) compared driving performance under a self-paced task (although not self-initiated) with driving performance under a controlled task during critical and non-critical events. Drivers were prompted at predetermined points in their route when to begin the tasks. In the self-paced task condition, drivers had 3 seconds to decide if it was more appropriate, given the driving situation, to accept or reject the task, whereas in the controlled condition, drivers had to engage with all tasks when prompted. Under the self-paced condition, drivers rejected more secondary tasks in critical situations as compared to non-critical situations, and exhibited better gaze behaviour toward the roadway. However, these behaviours did not lead to improved collision rates compared to the controlled condition. Although this study suggests that drivers try to be strategic on how they engage with distraction, it is not clear whether drivers are always effective at doing so. A closed track study by Horrey and Lesch (2009) gave participants a set number of tasks to perform while driving, but participants could initiate these tasks whenever they chose. They observed that drivers did not perform their tasks strategically and instead initiated tasks irrespective of the driving condition.

When drivers are engaged with a self-paced task, individual differences may become more apparent in how much they engage with the task and how much the task degrades their performance. Donmez, Boyle, and Lee (2007, 2010) gave drivers a self-paced, self-initiated, visual-manual task using a monetary reward system to incentivize drivers to engage with the task. While engaging with this task, drivers differed in how they modulated their visual attention to the task: drivers with more risky glance patterns toward the task exhibited shorter minimum time to collision than those with less risky glance patterns (Donmez, Boyle, & Lee, 2010).

To summarize, self-paced tasks are not used as often to study driver distraction as controlled tasks. There is evidence in the literature that when tasks are self-paced (in controlled experiments and naturalistic settings) they may still degrade driving performance, but that these performance degradations may differ from performance degradations observed under controlled tasks. Previous studies using self-paced tasks have observed individual differences in drivers' distraction engagement that may also affect driving performance, but it is unclear how and when drivers modulate their distraction engagement behaviour. Thus, there is a need to further study driver distraction using self-paced task studies to understand how more realistic forms of distraction engagement affect driving performance, and how individual differences may further affect driving performance and distraction engagement.

2.2.1 Facilitators of voluntary driver distraction

Previous research has indicated that intentional distraction engagement while driving may be influenced by driver characteristics such as demographics, attitudes, and beliefs. Younger drivers (16 – 24 yrs) are more willing to engage with potentially distracting activities than middle-aged and older adults (Lerner & Boyd, 2005), and older drivers have a harder time disengaging attention when shifting attention from one item to another (Cosman, Lees, Lee, Rizzo, & Vecera, 2012). Previous research on mobile phone use while driving showed that cell-phone engagement is associated with positive attitudes or positive evaluation of engaging in the secondary activity, such as the drivers' belief that using a mobile phone while driving is making effective use of their time (Walsh, White, Hyde, & Watson, 2008). Past behaviour, perceived strength of the driver's need to perform the task, the drivers' calibration of their own abilities, their confidence in their own driving performance while under distraction, their perceived risk or perceived effects of distractions, and their personality with respect to sensation seeking tendencies have also been associated with drivers' willingness to perform distracting activities while driving (Horrey & Lesch, 2008). In addition, self-reported voluntary distraction engagement frequency (as measured by SDDQ) is related to the Theory of Planned Behaviour constructs (Ajzen, 1991): higher self-reported voluntary driver distraction engagement frequency is related to positive attitudes, high perceived behavioural control, and positive perceptions of social norms related to voluntary driver distraction (Feng et al., 2014).

2.3 Previous research on driving under involuntary distraction

Involuntary distraction has been associated with car crashes (McEvoy, Stevenson, & Woodward, 2007; Wallace 2003), but as noted by Forster and Lavie (2008), much of the applied distraction research, including driver distraction, does not focus on irrelevant stimuli capturing attention. Most research examines distractions that require a response, and therefore cannot be ignored, or examines distracting effects resulting from secondary task interference by having the driver divide attention between two or more tasks (Forster & Lavie, 2008). Forster and Lavie (2008) and Sheridan (2004) all suggest that more applied research should address how, or the degree to which, involuntary attention to non-driving events effect driving performance. Sheridan (2004) states that research should further examine the degree to which voluntary and involuntary attention to non-driving events differ in their effects – a challenge addressed in this thesis.

Although there is little known research explicitly assessing involuntary distraction on driving performance, a closely related area of research examines the effects of electronic billboards on driving. Static or variable message boards may be irrelevant to the driving task and may cause involuntary distraction. However, because billboard content may attract drivers' interest, drivers may also attend to them due to exploratory attention selection (Figure 1). Simulator studies have found that driving on a road with billboards may degrade drivers' lateral control (Bendak & Al-Saleh, 2010; Chattington et al., 2009; M. Young & Mahfoud, 2008). In addition, M. Young and Mahfoud (2008) found that participants had more crashes and were less able to recall official road signs with billboards present than in a control condition. Bendak and Al-Saleh (2010) observed more instances of dangerous intersection crossings in the presence of roadside advertisements than in baseline driving and half of their participants self-reported being distracted by the signs near the intersections. Chattington et al. (2009) compared video advertisements with static advertisements and found that participants tended to brake harder and drive more slowly around video advertisements than they did near the static advertisements and in the control condition.

The effects of involuntary distractions caused by in-vehicle technology are even more understudied, and thus, these effects are not usually addressed by design guidelines. Current in-vehicle multi-functional infotainment technologies enable drivers to make phone calls, dictate and send text messages, play music, and navigate using GPS while driving. All this functionality may be accompanied by interface elements that can act as irrelevant stimuli. There are efforts to mitigate voluntary driver distraction: designers try to discourage drivers from intentionally performing complex tasks while driving by including mechanisms that restrict the use of particular functions while the vehicle is in motion. In addition, there are in-vehicle system guidelines that focus on drivers' intentional engagement through visual/manual interactions such as the *Visual-Manual NHTSA Driver Distraction Guidelines For In-Vehicle Electronic Devices* (National Highway Traffic Safety Administration, 2013) which attempt to reduce the demands of infotainment systems. However, designers and guideline authors have paid less attention to the potential distraction inherent in displaying content within the driver's field of view, even when the driver is not intentionally interacting with the interface. It is possible that this issue will become more problematic as more salient types of content and displays enter the marketplace.

2.4 Driver distraction and attention mechanisms

Two well-established theories of attention and cognition exist that may facilitate understanding when and why voluntary and involuntary distraction affect drivers and what modulates the size of these effects. These theories are Multiple Resource Theory and Load Theory. Multiple Resource Theory (Wickens, 2002) states that humans' cognitive, perceptual, and motor resources are finite. If two time-shared tasks compete for similar resources, then dual-task interference is more likely to occur than if the tasks use different resources. Interference can cause one or the other concurrent task's performance to degrade below the single task baseline level. Nevertheless, if two tasks use different resources they may still incur a 'cost of concurrence', if overall resource demands are high (Wickens, 2002). The multiple resource model (an application of multiple resource theory) uses four dimensions to account for variance in performance of time shared tasks. There may be greater interference between tasks that share resources along a single dimension than those that do not (Wickens, 2002). These dimensions are

- processing stages (perceptual and cognitive versus response)
- sensory modalities (auditory versus visual)
- visual channels (focal versus ambient), and
- processing codes (visual versus spatial).

Perceptual and cognitive processing stages and visual sensory modalities are the resources that will most likely be shared, and thus create interference, between the driving task and driver distraction.

Driving is a highly visual and motor activity and, due to the sharing of sensory modalities, there is evidence that visual and psychomotor distractors affect drivers' safety more than auditory and/or cognitive tasks. Greater lane deviation was observed when participants manually dialed on a mobile phone than when they were talking on the phone or were dialing using voice commands (Serafin, Wen, Paelke, & Green, 1993). Participants travelling on curved roads exhibited worse performance in steering wheel control and lane keeping while performing a visual secondary-task than when performing auditory and cognitive secondary tasks (Hurwitz & Wheatley, 2002). Although the driving task is highly affected by visual-manual tasks, auditory and speech response tasks can still interfere with the driving task. For example, Haigney et al. (2000) found hands-free phone interaction to require significant attentional resources due to the cognitive effort of the task.

Although concentrating on the task at hand is necessary to complete a task efficiently and effectively, from a survival perspective, it is natural that overrides exist to capture and orient attention towards unexpected and potentially important or dangerous stimuli (Parmentier, 2008). Irrelevant stimuli may also capture attention as humans search for optimal arousal potential between under-arousal (boredom) and over-arousal (stress) (Berlyne, 1960). Information can modify arousal (Berlyne, 1960), so people may seek out more information when under-aroused or seek to remove information when over-aroused.

Load Theory states that perception is a capacity-limited process that proceeds in an automatic manner on all stimuli within its capacity, and people cannot control this mechanism. Distraction rejection is dependent on the current level and type of load: in tasks with low levels of perceptual load, spare capacity not used by the task-relevant stimuli involuntarily "spills over" to the perception of task-irrelevant distractors. When the primary task requires high perceptual load (e.g., tasks involving many relevant stimuli), distractor processing is prevented because perceptual load capacity is exhausted. There are special stimuli that may override the effects of perceptual load, possibly due to an increase in task relevance (Forster & Lavie, 2008).

Overall, Load Theory focuses on perception and how an irrelevant stimulus may be less likely to capture attention if attentional resources are at full capacity. Multiple Resource Theory explains how task performance may suffer if resources are overloaded beyond capacity, and these resource conflicts can include interference between perception and cognitive processing (which, although they are at different stages of information processing, share a common resource) or interference between tasks requiring similar sensory modalities (Wickens, 2002). Both these theories relate to distractor inhibition: high perceptual load may reduce distractor interference, but since cognitive resources are required to prioritize stimuli importance, if there is a high cognitive load, this prioritization mechanism may suffer and irrelevant stimuli may be processed. A series of experiments by Lavie et al. (2004) demonstrated that high perceptual load reduces distractor interference as long as cognitive load is low enough that cognitive control functions are available to maintain processing priorities.

When considering secondary tasks while driving, e.g., a cellphone conversation, it is logical to assume that drivers will attempt to strategically reallocate attention from the processing of less relevant information in the driving scene (e.g., billboards) to the secondary task (e.g., cellphone conversation) while continuing to give the highest priority to the processing of task-relevant information (e.g., the car in front of them). However, there is evidence that drivers do not optimally allocate attention: Strayer et al. (2003) observed that participants looked at billboards equally often in both single and dual task conditions. An irrelevant stimulus, such as a billboard, may distract drivers' attention to the extent that it increases the probability of a crash, and this effect might be mediated by the level of cognitive demand imposed on the driver by the driving task and any other tasks he is performing (Wallace, 2003).

2.4.1 Factors that contribute to automatic attention capture

The intrinsic qualities of an irrelevant stimulus, the nature of the primary task, and drivers' cognitive abilities may all affect drivers' susceptibility to involuntary driver distraction.

Intrinsic qualities of an irrelevant stimulus: Abrupt onsets, high luminance, moving objects, looming objects, and new objects are highly salient and are more likely to capture attention even when they are irrelevant (Franconeri & Simons, 2003, 2005; Hollingworth, Simons, & Franconeri, 2010; Yantis & Jonides, 1990). Salient stimuli may capture attention automatically (Yantis & Jonides, 1990), and unexpected and novel stimuli are particularly powerful at capturing attention. Parmentier (2008) found that the novelty effect of an unexpected auditory stimulus can disrupt an unrelated visual task by shifting attention to the novel sound where rare auditory stimuli are presented among otherwise repeated sounds. Unexpected stimuli can overwhelm suppression attempts and distraction may occur both automatically and unconsciously (Irwin, Colcombe, Kramer, & Hahn, 2000; Theeuwes & Godijn, 2001). Several studies demonstrated that humans cannot ignore sudden and unexpected stimuli (e.g., visual, tactile, auditory) regardless of their irrelevance to the primary task (Sheridan, 2004). The value of the stimuli may also influence the bottom-up attention selection process where stimuli that are more meaningful to an individual, such as their name, are more likely to be captured as illustrated by the cocktail party effect (Cherry, 1953; Moray, 1959). In addition, an individual's ability to inhibit irrelevant information varies significantly from person to person (Murphy, 2002). Therefore, drivers may be distracted by a stimulus even though they have no intention to engage or respond to it, depending on their ability to suppress the stimulus.

Nature of the primary task: The attributes of the primary task and the primary task environment can also alter distractor interference. A high cognitive-control load, in other words, a load on the executive cognitive control function such as working memory, can increase distractor interference. Increasing cognitive-control load may prevent people from actively maintaining stimulus-processing priorities during task performance that help distinguish targets and distractors, by rendering the resources that would normally do this prioritizing task unavailable (Lavie, 2005). On the other hand, as mentioned earlier in this section, a high perceptual load for processing task-relevant stimulus that engages full attentional capacity can reduce distractor interference. However, increasing perceptual load should not be confused with increasing task difficulty by mechanisms such as limiting data quality (e.g., increasing task-relevant stimuli processing difficulty by reducing size or contrast) which causes performance degradation but does not reduce distractor interference (Lavie, 2005). In addition, masking the irrelevant stimuli through noise may reduce distractor interference: if patterned stimuli can be masked by sustained noise stimuli of sufficient magnitude, then the irrelevant stimuli may be more easily ignored (Sheridan, 2004).

Drivers' cognitive abilities: In driving, where roadway environments can be highly complex and there are many stimuli that afford attending to, drivers must selectively attend to task-relevant stimuli (e.g., traffic signals or bicyclists) and ignore, or suppress, irrelevant stimuli (e.g., roadside advertisements) in order to safely operate a vehicle. Thus, drivers' responses to involuntary distraction may vary based on their attentional and perceptual capabilities. The ability to inhibit irrelevant information varies significantly among individuals (Murphy, 2002) and laboratory studies measuring drivers' selective attention abilities using cognitive tasks have found these abilities to predict traffic crashes (Arthur & Doverspike, 1992).

Inhibition has been defined as the "ability to deliberately inhibit dominant, automatic, or proponent responses when necessary" (Miyake et al., 2000). This definition was extended by Friedman and Miyake (2004) to distinguish among three types of inhibition. (1) Inhibition of a prepotent response is the ability to deliberately suppress dominant, automatic, or prepotent responses. (2) Resistance to distractor interference is the ability to resist or resolve task-irrelevant information from the external environment. (3) Resistance to proactive interference is the ability to resist intrusions from information stored in memory that was once relevant to the task, but is no longer relevant. Drivers with lower inhibition capacities (specifically inhibition of a prepotent response and resistance to distractor interference) may be more susceptible to involuntary distraction.

The Stroop (Stroop, 1935) and the flanker tasks (Eriksen & Eriksen, 1974) are common tasks used to assess inhibition abilities. The Stroop task measures inhibition of a prepotent response by measuring the time it takes for participants to name the colour of the ink in which an incongruent word is presented (e.g., the word BLUE in red ink). The automatic reading behaviour interferes with the naming of the ink colour, resulting in a slowed response. The flanker task measures resistance to distractor (irrelevant stimuli) interference by measuring response times to a centrally presented target stimulus that is flanked by distractors that may activate the same response channel as the target. Studies have found that response times are higher when the flanker stimuli are incongruent (as opposed to congruent). This effect, known as the *flanker compatibility effect*, indicates that the distractors are processed even though they are irrelevant to the task (Eriksen & Eriksen, 1974; Roper, Cosman, & Vecera, 2013). In addition, a self-reported measure that is relevant to measuring individual differences in inhibition is the Cognitive Failures Questionnaire (CFQ) (Broadbent et al., 1982). The CFQ is a common self-reported measure of cognitive limitations and attentional capacity in everyday situations. Friedman and Miyake (2004) found that higher CFQ scores (increased self-reported cognitive failures) are related to lower inhibition of prepotent responses and higher resistance to distraction interference. The relationships between CFQ, prepotent response inhibition, and distraction resistance were expected to arise because many of the cognitive failures participants report on in CFQ are the result of lapses, often due to distraction, that allow automatic responses to take priority over appropriate or intended responses (Friedman & Miyake, 2004).

2.5 Altering involuntary driver distraction through varying perceptual load

Identifying which driving environments create an increased susceptibility to involuntary distraction can be useful in the design of mitigation strategies; one environmental characteristic of interest is the level of perceptual load. As mentioned earlier, in other domains, increasing cognitive load has been shown to increase the attention capture potential of unexpected irrelevant stimuli, but increasing perceptual load has been shown to reduce attention capture. Controlling the perceptual load in a driving scene can be complex and it can be difficult to increase perceptual load without increasing cognitive load. Driving studies where road environment complexity was varied were examined for possible ideas on how to vary perceptual load levels in order to test whether the findings on perceptual load in other domains also applies to the driving domain. The following sections outline some of those ideas.

2.5.1 Curved roads

Driving around a curve requires extra visual attention compared to straight road driving; attention must be focused on lane markings and road edges to acquire the information required to navigate a curve safely. In contrast, straight road lane markings can be monitored peripherally to steer appropriately (Ady, 1967; Land & Lee, 1994; Shinar, McDowell, & Rockwell, 1977). Thus curvature in the road may seem like an ideal candidate for varying perceptual load capacity in driving. However, in his review, Wallace (2003) noted that Ady (1967) found a significant increase in accident rates between the year prior to and the year after an advertising sign was erected. This sign was illuminated by bright white lights making it highly conspicuous and was located at the corner of a sharp bend. On the other hand, he did not find a significant increase for signs placed on less complex road configurations. Given that increasing cognitive load causes an increase in interference from irrelevant low-priority distractions due to the overloading of resources that would normally be prioritizing and helping filter low-priority stimuli (Lavie, 2005), the finding that the advertisements affected drivers’ performance on the curved road but not in the less complex road configurations could indicate that curves add to cognitive load. Thus, because of the confounding of perceptual and cognitive load factors, curved roads may not be ideal for testing how perceptual load modulates drivers' ability to suppress irrelevant stimuli in the driving context.

2.5.2 Traffic density

Modifying traffic density is another way to alter the load imposed by the driving environment. Forster and Lavie (2008) suggest that drivers may be less susceptible to distraction from salient billboards while weaving in and out of heavy traffic (high perceptual load) versus driving along an empty motorway (low perceptual load). According to Load Theory, the high perceptual load of maneuvering through heavy traffic would reduce the interference of the irrelevant stimuli in perceptual tasks. Thus increasing traffic density may be a way to increase the perceptual load of the driving task.

2.5.3 Visual clutter

Visual clutter may have an effect of increasing perceptual load or it may act as a distractor in its own right. In general, visual clutter increases visual search time (Boersema, Zwaga, & Adams, 1989). Horberry et al. (2006) studied the effects of clutter in the driving context and had drivers perform a secondary task in two environmental complexities. The complex condition contained 12 times as many buildings, oncoming vehicles, and other highway furniture compared to the simple condition. The secondary task degraded performance but environment complexity did not change this effect. Thus, increasing clutter may also increase task-relevant perceptual load without overly increasing cognitive load.

2.6 Summary

Distracted driving compromises the safety of all road users. Distractions may stem from intentional engagement in secondary tasks (voluntary distraction) or the inability to suppress non-driving related information even when the driver does not intend to engage with such stimuli (involuntary distraction). Although involuntary distraction has been the subject of prior research in other fields, the existing research in the driving domain has been very limited, mostly to roadside advertisements. Further, driver distraction is generally studied through tasks imposed on the driver and there is a need to further investigate intentional distraction engagement by allowing participants to self-regulate the initiation and pace of secondary tasks.

This body of work examines the effects of voluntary (Experiment 1) and involuntary (Experiments 1 and 2) distraction on drivers in simulated driving and the factors that alter these effects. The modulating factors explored are (1) the individual driver characteristics that may play a role in their susceptibility to driver distraction (Experiments 1 and 2), and (2) the perceptual load level in the driving environment as it relates to involuntary distraction effects (Experiment 2).

Chapter 3

3.0 Experiment 1

3.1 Summary

In this first experiment, 36 participants were observed under three distraction conditions: driving while performing a self-paced task on a secondary display (voluntary distraction), driving while unexpected irrelevant stimuli appeared on the secondary display (involuntary distraction), and a baseline condition with no distractions. The participants also filled out SDDQ, which collected data on self-reported frequency of distraction engagement. In each experimental condition, the driver was tasked with maintaining the speed limit while following a lead vehicle, which braked multiple times throughout the drive. Under involuntary distraction, participants' accelerator release times (ART) in response to lead vehicle braking were delayed, leading to shorter minimum time to collision (TTC_{min}) values. However, there were no differences in how quickly the participants glanced at the lead vehicle after its brake onset suggesting that the delay in ART may not be due to a delay in perception but rather a cognitive delay or a lack of perceived urgency. Under voluntary distraction, participants also experienced ART delays. However, there was also a marginally significant decrease in their transition time from the accelerator to the brake pedal (i.e., "brake transition time" or BTT), a potential compensatory mechanism, which led to TTC_{min} comparable to the baseline condition. In contrast to involuntary distraction, participants might have been more conscious of the potential negative effect of distraction when they voluntarily engaged in it. Supporting this hypothesis, participants also maintained lower speeds under voluntary distractions, but not under involuntary distractions. In terms of individual differences, participants who self-reported higher frequency of engagement in voluntary distractions in real world driving glanced more frequently at the secondary display in the voluntary distraction condition.

3.2 Method

3.2.1 Participants

38 participants (19 females, 19 males) were recruited for this experiment. Recruitment tools included online, email, and poster advertisements (Appendix A). Participants had normal or corrected-to-normal vision, a valid full Canadian driver's license, and were between 25 and 39 years old ($\bar{x}$ = 29.2, SD = 4.1). Participants were selected based on a screening survey

administered prior to the experiment (Appendix B). The survey was used to assess if participants with corrected vision could use contact lenses (as the glare from glasses reduced the accuracy of the eye tracking hardware) and if they were prone to simulator sickness (recruitment of individuals who were prone to indicators of simulator sickness was avoided).

Participants were also recruited based on their self-reported frequency of engagement in distracted driving. This construct was measured using SDDQ (Feng et al., 2014). Participants answered questions regarding how frequently they engaged in a list of six distractions: “When driving, you: (1) hold phone conversations, (2) manually interact with a phone, (3) adjust the settings of in-vehicle technology, (4) read roadside advertisements, (5) continually check roadside crash scenes if there are any, and (6) chat with passengers if you have them.” Participants responded to these items on 5-point Likert scales ranging from ‘never’ to ‘very often’ (Appendix C). The average of responses across all six items was used to describe participants’ level of self-reported distraction engagement (SRDE). In order to recruit more participants from the tail ends of the engagement distribution, participants were selected based on pre-defined ‘level of engagement’ bins. Thirty-six participants were used in the analysis: twelve participants were selected who scored as having high [3.5, 5), twelve as having medium [2.8, 3.2), and twelve as having low [1, 2.6) SRDE. Two participants from the original 38 that were recruited were removed from the final analysis. One participant experienced symptoms of driving simulator sickness and withdrew from the driving experiment. The other participant was incorrectly recruited with a SRDE score outside of the pre-determined bins (score = 3.3). Participants were compensated $15/h for their participation and were provided with an additional $5 for study completion.

3.2.2 Apparatus

A NADS quarter-cab MiniSim™ Driving Simulator was used for the study (Figure 2). This fixed-based simulator has three 42” widescreen displays, creating a 130° horizontal and 24° vertical field of view at a 48” viewing distance. The simulated driving experiment was developed using the MiniSim Software Suite. The road network was created using the Tile Mosaic Tool and the driving scenarios were created using the Interactive Scenario Authoring Tool. The simulator collects driving measures at 60 Hz.

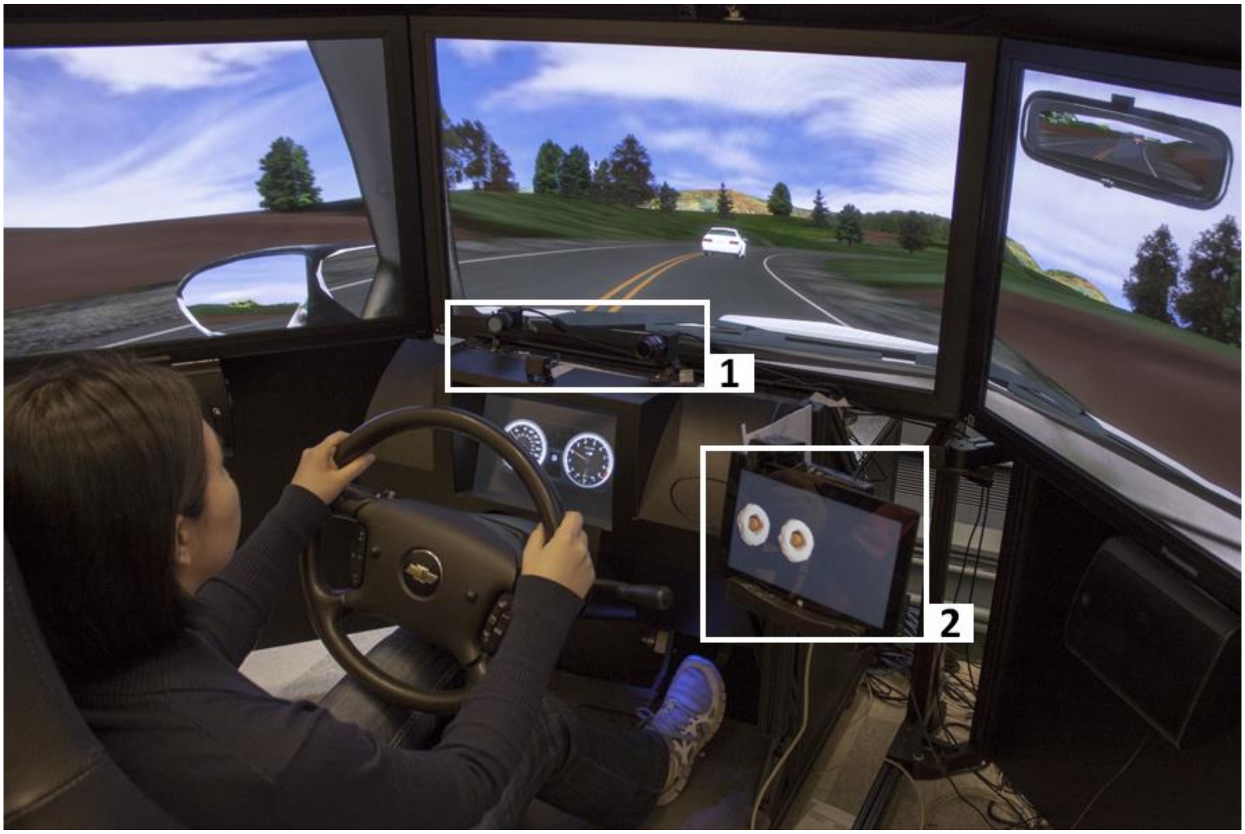


Figure 2: Simulator setup with faceLab eyetracker (1) and Surface Pro 2 (2) where the distracting stimuli were displayed during the experiment

A Microsoft Surface Pro 2 was used to display the involuntary distraction stimuli and the self-paced secondary task (described below). The Surface Pro 2 was positioned to the right of the dashboard where it would not be visually obstructed by the steering wheel. A dashboard mounted faceLAB 5.1 Eyetracker collected gaze data. The eye tracking hardware uses two cameras mounted on top of the simulator dashboard as a passive measuring device. The eye tracking software analyses images from the cameras to generate data on eye movements, eyelid aperture, pupil size, etc. These images are processed by faceLAB at 60 Hz. The gaze tracking has a range of ±45° around the y-axis (horizontal range) and ±22° around the x-axis (vertical range). The typical static accuracy of gaze direction measurements is 0.5° to 1°. Seeing Machines' faceLAB 5 eye-tracking system was integrated with both the simulator software and EyeTracking Inc.'s EyeWorks software. The EyeWorks software synchronizes the gaze data with the video on the simulator's centre display. Video output is generated which shows the participant's gaze location and a trail representing a 500ms gaze trail leading up to the gaze location.

3.2.3 Experiment design

Experiment 1 used a 3x3 mixed design with SRDE category as a between subject variable and distraction type as a within-subject variable. As presented previously, three groups of participants were selected for this study based on high, medium, and low levels of SRDE. Three distraction types were tested in three separate drives: baseline with no external distraction, voluntary distraction induced through a self-paced secondary task, and involuntary distraction generated through a stimulus which had an abrupt onset and did not require any interaction. The order of experimental drives was counterbalanced across participants (Appendix D).

3.2.4 Voluntary distraction task

The secondary task used in the voluntary distraction condition is a self-paced visual-manual task adapted from a task developed by Donmez, Boyle, and Lee (2007). The task mimics drivers' interactions with in-vehicle systems (e.g., scrolling through location options in a navigation system) and has been shown to affect driving performance: drivers exhibited delayed accelerator release times (about 0.4 seconds) in response to a braking lead vehicle when under distraction conditions as compared to a condition without the task available (Donmez et al., 2007).

The task was a word matching task and was presented on the Surface Pro 2 (Figure 3a). Participants needed to select one phrase out of 10 phrases that matched the target phrase "Discover Project Missions". A phrase qualified as a match if any of these three conditions were met: "Discover" was in the first position, "Project" was in the second position, or "Missions" was in the third position. Thus "Discover Missions Project" is a match because it has "Discover" first, whereas "Project Discover Misguide" is not a match because none of the target words are in the correct place. There was only one correct answer in the list of ten candidate phrases, and participants could tap the up and down arrows with their fingers to scroll through all the options. Only two options were displayed at one time. Participants entered their choice by pressing the submit button and received feedback on whether their choice was correct or incorrect. The task was available throughout the drive and participants could choose when to start a new task. Participants were told to perform the task only when they felt comfortable doing so and that, since the experiment was not investigating risk taking, they should prioritize driving safety as they normally would in real-world driving.

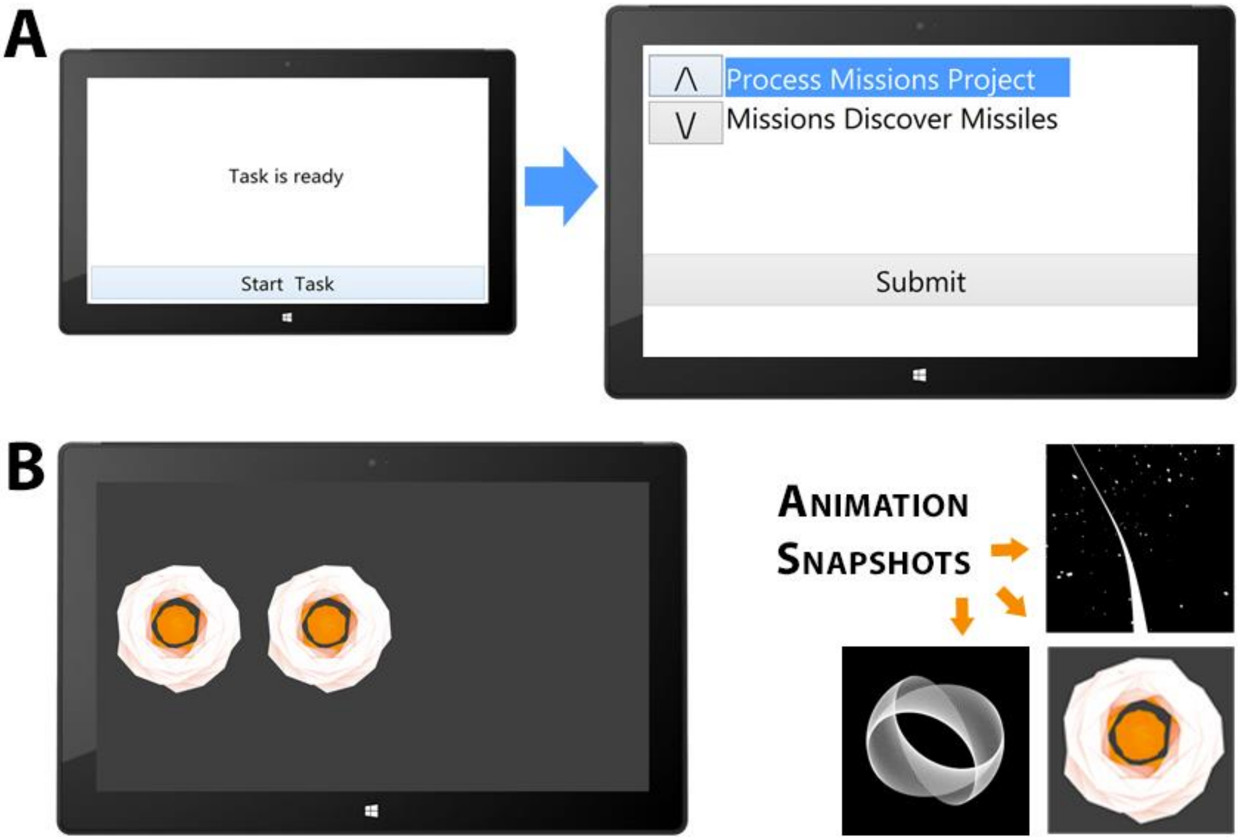


Figure 3: (A) The voluntary distraction as it appears on the 208 dpi secondary display. (B) The involuntary distraction as it appears on the secondary display. Each animation was 500x500 pixels and was displayed once per drive. These animations were sourced from: http://www.89a.co.uk/post/34407365222/doughnut, http://staytrippy.de/post/84021641879/dream-drugs-rule-everything-around-me, and http://www.89a.co.uk/post/57500880753/spiropath

3.2.5 Involuntary distraction stimuli

Involuntary distraction stimuli were developed specifically for this study. The distractions were designed to not have a voluntary component and to capture attention (Figure 3b). Past research has shown that salient stimuli capture attention automatically even when these stimuli are irrelevant and that stimuli with abrupt onsets are more liable to cause this effect (Yantis & Jonides, 1990). The final design was a chime sound followed by an abrupt onset of a 5 second geometric animation. This distraction occurred 11 times during the drive at fixed locations along the roadway (Figure 5): one of three animations developed was selected randomly and displayed. Prior to the involuntary distraction drive, drivers were told that they did not need to interact with the display when it played the animation and sound.

3.2.6 Driving scenario

Each experimental drive used the same road network and took approximately 10 minutes to drive through. The road network had a rural environment for the first half of the drive and an urban environment for the second half (Figure 4), although the effect of environment was not studied in Experiment 1 (the order of the environments was not counterbalanced). The simulated road (both lanes) was modeled to be 12 feet, or 3.66 m, across. The rural driving environment was characterized by a posted speed limit of 50 mph (80.47 km/h) and a two-lane highway with a shoulder on each side of the roadway and yellow lines separating opposing traffic flow. Participants were instructed to maintain 50 mph in the rural environment. The urban driving environment consisted of six intersections separated by straight, four-lane roads, divided by a double solid line, with more visual clutter than the rural environment, including parked cars, buildings, and stationary pedestrians on each side. The posted speed limit was 35 mph (56.33 km/h). Participants drove straight through four intersections and turned left at two intersections.

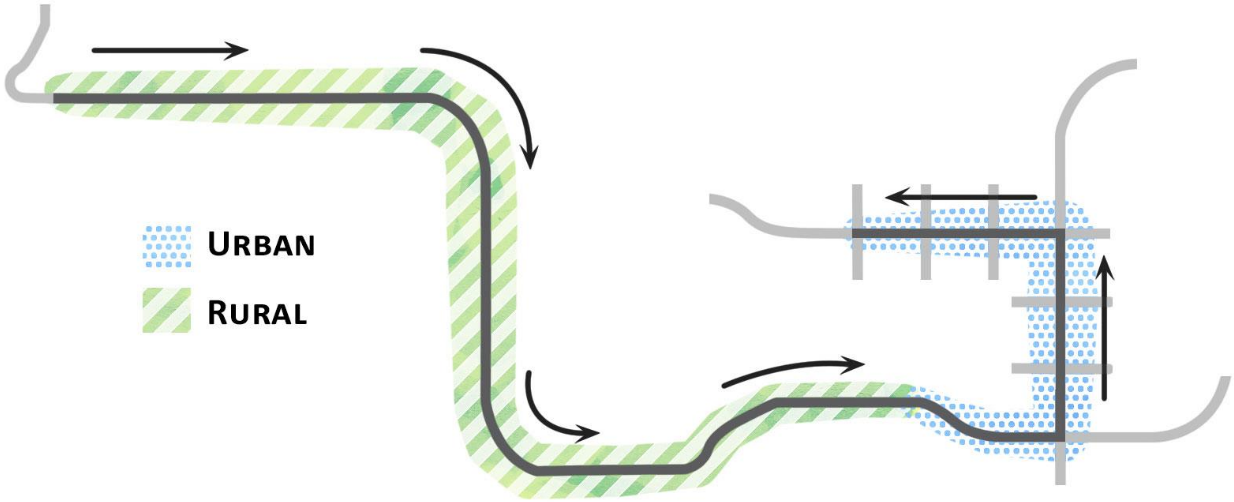


Figure 4: The direction of travel and surrounding driving environment of the Experiment 1 road network

Multiple driving events occurred during each experimental drive (Figure 5). These events were the same for each drive, but locations varied from one drive to the next. The events were selected based on their past use in distracted driving studies to increase the magnitude of driving performance degradation under distraction conditions. The focus in this thesis is on lead vehicle braking and gap acceptance events. There were also two hazards (pull-out car and bicycle crossing) that were tested but are not reported. These two hazards are not reported because infrastructure leading up to the hazardous events confounded the results of the car and bicycle events, as the participants could anticipate these hazards based on road design elements. The involuntary distraction stimuli were triggered at 11 fixed locations in the involuntary distraction condition drive. In the rural region, four instances were synchronized by location with the four lead vehicle braking events, one stimulus happened prior to the bicycle crossing events, and two happened near dummy bicycles that did not cross the road. In the urban environment, two instances occurred along with the two gap acceptance tasks, two occurred along straight road sections, and two occurred prior to the intersections from which the right turning incursion vehicle could emerge.

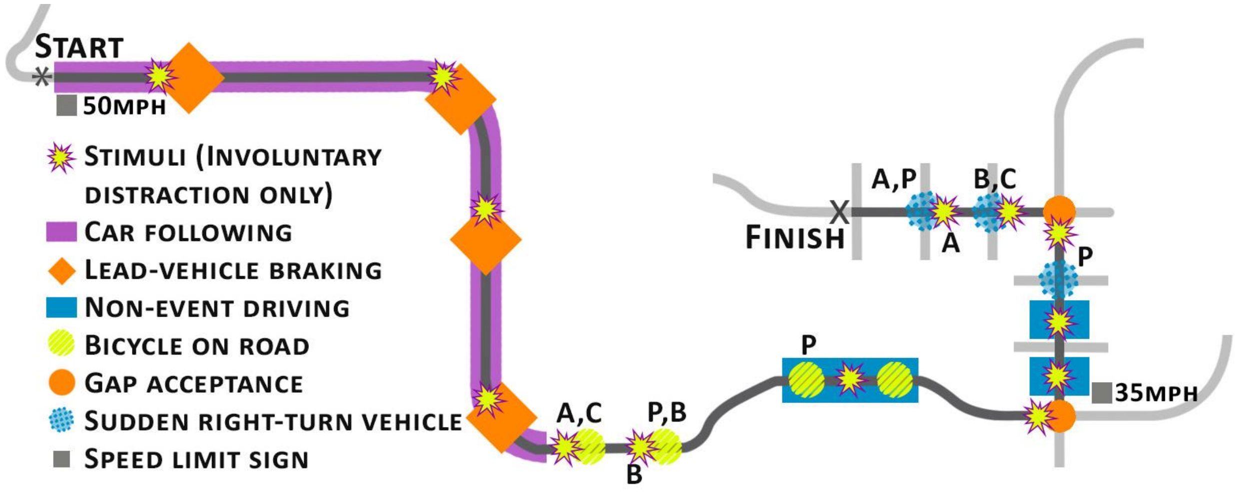


Figure 5: Event locations in the simulated drive. Bicycle and sudden right-turn vehicle events only occurred once in each drive, the locations of which are marked as A, B, or C corresponding to the first, second, and third experimental drives. P denotes the location of events in the practice drive.

Lead vehicle braking events were used to capture the effects of distraction on perception and reaction time (Figure 6). Increased time to release the accelerator pedal in response to a lead vehicle braking event has been observed previously when drivers were distracted by the self-paced task used in this experiment (Donmez et al., 2007). There were four lead vehicle braking events within the rural section of each drive. At 730 feet before lead vehicle braking onset, the lead vehicle speed was smoothly adjusted to obtain a time headway of 1.8 s between the lead vehicle and the participant's vehicle. During adjustment, lead vehicle speed was restricted to a maximum (80 mph) and minimum (35 mph) to avoid excessive speeding or slowing down during the headway adjustment. Headway control ceased at pre-determined braking locations along the roadway where the lead vehicle brake lights turned on and the lead vehicle braked at a rate of 0.2 g (gravitational acceleration) for 7 seconds.

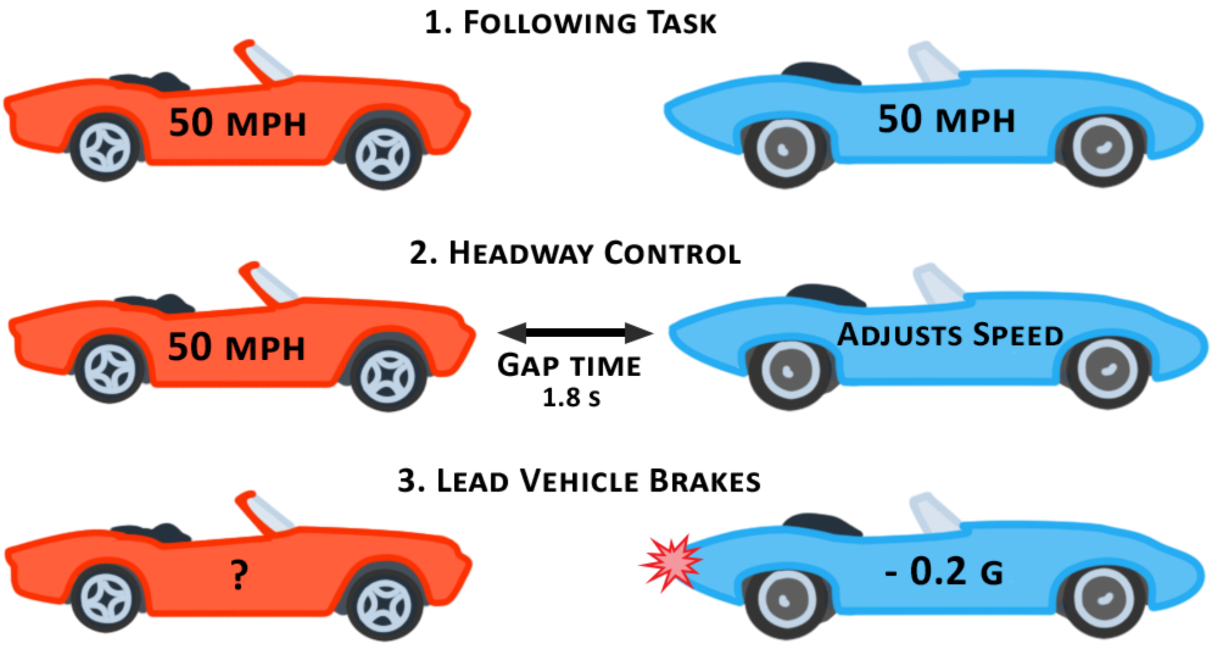


Figure 6: Experiment 1 lead vehicle braking event design

A left-turn gap acceptance task was used to capture the effects of distraction on decision making while driving. Participants had to make a left turn through oncoming traffic at an intersection with a designated left-turn lane where the light remained green. 16 cars drove through the intersection at approximately 40 mph. Participants had 15 gap times to choose from, in the following order: 2, 4, 6, 3, 5, 7, 2, 4, 6, 3, 5, 7, 8, 9, and 10 seconds. These values were chosen based on an augmented reality study by Moussa, Radwan, and Hussain (2012) that assessed gap times that drivers would accept when completing a left turn, while driving a real vehicle on an actual road across virtual traffic overlaid on top of the driving scene. Participants were instructed to make their turn when they felt comfortable doing so.

3.2.7 Procedure

The simulator study was administered as part of a larger experiment. All participants first completed a modification of the flanker task, followed by the simulator study, and concluded with the operation span task (ospan; Turner & Engle, 1989), which assesses working memory capacity. A questionnaire on perceived multi-tasking ability was administered after the ospan task, in addition to a repetition of SDDQ to assess its test-retest reliability (SDDQ had already been administered as part of the screening process). The results from the ospan, perceived multi-tasking ability, and SDDQ repetition were used to help validate SDDQ as part of a second project and are beyond the scope of this thesis. The flanker results were also not analyzed as the modifications applied to the flanker task made the task invalid[1]. The experiment took approximately 3 hours.

Prior to driving, the experimenter guided the participant through the following: informed consent (Appendix E), calibrating the eye tracker for the individual participant, providing further warnings about simulator sickness, giving participants an overview of the experiment, teaching the participant how to perform the voluntary task, and acclimatizing the participant to the dynamics of the simulated environment (see Appendix F for the experimenter guidelines). The participants practiced 5 voluntary tasks on the secondary display (i.e., five lists of 10 phrases) prior to driving. Participants were shown the layout of the experimental drive using a map and were told to follow the lead car maintaining a speed of 50 mph unless the lead car braked with its brake lights on, where to make left turns, and when the speed limit changed to 35 mph. Participants were instructed that their main task was to operate the vehicle safely and to drive as they would in their own vehicle.

After these setup activities, participants drove through a practice drive with the secondary task available: participants were encouraged to try at least two tasks during the practice drive. The practice drive was used to help acclimatize participants to the dynamics of the simulation

---

[1] In an effort to improve participants' accuracy in identifying the direction of the target shape, the flanker and target graphics were altered from "T" shapes to ">" and "<" shapes (see section 4.4.3.2 for a detailed description of the flanker task). However, these visual changes appear to have fundamentally changed the flanker task as it did not produce a statistically significant flanker compatibility effect (defined previously in Chapter 2) at $p < .05$.

environment (Caird & Horrey, 2011; Strayer, Cooper, & Drews, 2011). During the practice drive, participants were exposed to all the driving scenarios present in the experimental drives, including car following, left-turn gap acceptance, and pull-out car and bicycle crossing hazards (practice drive hazard locations are denoted by a "P" in Figure 5).

After finishing the practice drive, participants then drove through the three experimental drives. Prior to **each drive**, participants were told: *"Your main task in this study will be the safe operation of the vehicle. Please drive as you would in your own vehicle and prioritize safety as you would in your own vehicle."* Before driving through the **voluntary distraction** condition, participants were given the following instruction: *"During the drive, this task will be available at all times. You can choose when to perform the task. Perform the task only when you feel comfortable doing so and at a pace that you are comfortable with. This is not an experiment in risk taking; your primary task, as in the real world, is to drive safely at all times so please prioritize driving as you normally would."* Prior to the **involuntary distraction** drive, participants were instructed: *"For this drive, there will be a sound and an animation that appears on the display periodically. You do not need to interact with it."*

During the drives, participants were told by the experimenter when they no longer needed to follow the lead vehicle and were reminded when to make left turns at the upcoming intersections. After each experimental drive, participants filled out a questionnaire to assess the perceived risk of the drive (Tsimhoni, Smith, & Green, 2003) and the NASA-TLX Mental Workload Rankings to assess perceived workload (Hart & Staveland, 1988, Appendix G).

3.3 Measures

3.3.1 Self-reported measures of engagement from SDDQ

Participants' responses to SDDQ were collected along with the screening survey information. The involuntary distraction section of SDDQ asks the responders to rate whether they found potential involuntary distraction items distracting while driving (Appendix C). These items were measured from 1 to 5, anchored at 'strongly disagree', 'disagree', 'neutral', 'agree', and 'strongly agree'. Distraction items that a participant responded 'never happens' to were removed from the calculation of the average involuntary distraction score. A higher score indicates higher self-reported susceptibility to involuntary driver distraction.

As mentioned previously, participants were recruited based on their responses to the SRDE questions from SDDQ. These questions asked participants to report the frequency with which they engaged with certain secondary tasks while driving. A higher score indicates higher self-reported susceptibility to voluntary driver distraction.

3.3.2 Distraction engagement metrics in simulated driving

Table 1 provides a summary of the distraction engagement metrics measured in the driving simulator. For the relevant glance metrics, only glances over 100 ms were used in the analysis as shorter glances may be transition data that do not represent proper fixations on the distraction target (Horrey & Wickens, 2007). Glance duration was defined as the time from the direction of gaze moving toward the target (the Surface Pro 2 where the distractions were displayed) to the moment the gaze moved away from it (i.e., fixation time plus transition to the target) (ISO Standard 16673:2007). Glance data were manually coded using video recorded from the Surface Pro 2’s camera. Similar to a coding technique used by Mehler et al. (2014), this manual glance coding was performed by two trained independent coders and a mediator who settled differences in the coding. Each coder was trained using a step-by-step tutorial developed to teach the coders how to use the video coding software (Datavyu 1.1), the definitions of a glance, and how to identify and record glances toward the secondary display. This manual coding was supplemented with eye tracking data when necessary.

Table 1: Distraction engagement metrics and definitions

Distraction Engagement Metric	**Definition**	**Unit**
Number of glances	Number of glances over 100 ms participant made to the Surface Pro 2 while driving in a region of interest	integer
Average glance duration	Average time of glances toward the Surface Pro 2 while driving through a region of interest	milliseconds
Total glance duration	Total time participant glanced at Surface Pro 2 while driving through a region of interest	milliseconds
Glance initiation time	Time until first glance toward the involuntary distraction stimulus after stimulus onset	milliseconds
Number of taps	Number of times participants physically tapped the Surface Pro 2 to interact with the voluntary distraction task	integer
Tasks completed	Number of voluntary distraction tasks (one list of 10 phrases) completed	integer
Average task time	Average time between when participants started a voluntary distraction task and finished that task	milliseconds
Average time between tasks	Average time between when participants finished a voluntary distraction task and started a new one. This metric includes the time it took for participants to start their first task after it became available.	milliseconds

3.3.3 Driving measures for lead vehicle braking

The perception and response times for lead vehicle braking events were divided into different components as illustrated in Figure 7 and described in Table 2; braking metrics followed SAE J2944 (2015)[2]. The onset (or start) of the lead vehicle braking event is defined as the point when the brake lights of the lead vehicle turned on and the lead vehicle began to decelerate. The lead

---

[2] While the intention is to follow SAE J2944 measures and abbreviations as closely as possible, it is noted that the measures used in this thesis often reflect variables that are more specific than those described in SAE J2944, with the exception of TTCmin. For example, this study’s "brake transition time" (BTT) falls under the SAE J2944 Movement Time (MT, “Time interval, usually measured in seconds or milliseconds, for the responding foot or hand to move from one location to another”), but is more specific in identifying the locations involved, i.e., from the accelerator pedal to the brake pedal.

Further, perception time and inspection time are not explicitly defined in SAE J2944, but were used in the report because it was of interest to identify when the participants observed lead vehicle braking. The term perception-response time is used in SAE J2944, but is restricted to situations involving an emergency braking response.

vehicle's deceleration started at the same time that its brake lights illuminated. Accelerator release time (ART) was calculated from lead vehicle brake light onset to the time the accelerator pedal was completely released, referred to in the remainder of this document as ART. The relevant metric in the SAE J2944 is described as follows: "time from an initiating event until the foot (initially on the accelerator pedal) is no longer in contact with the accelerator pedal or when the accelerator position signal reaches zero, if the movement is in response to that event". Response time until brake contacted, referred to in the remainder of this document as BRT, is the time between the event onset and the moment contact was made with the brake pedal (SAE J2944, 2015). All driving performance metrics were recorded by the simulator at 60 Hz.

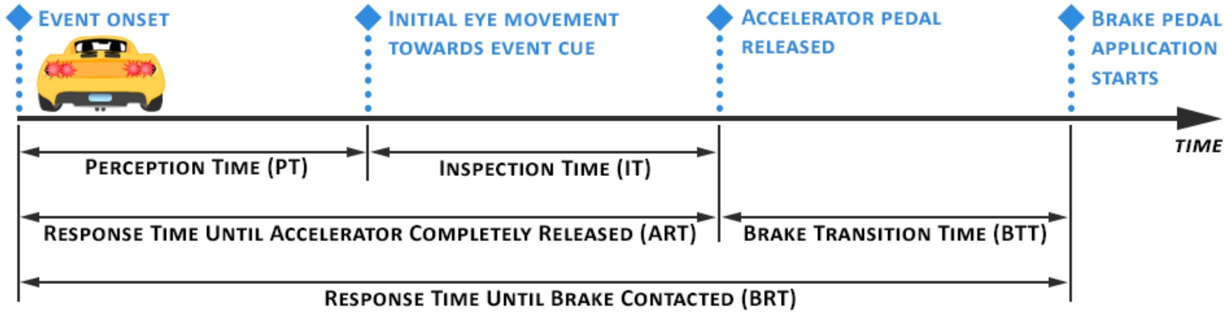


Figure 7: Braking and glance responses to lead vehicle braking events as they occur in time with respect to the event onset

The start of the first continuous eye movement towards the lead vehicle after the lead vehicle braking event onset was used to further divide ART into perception and inspection times. As mentioned previously, the EyeWorks software synchronizes the gaze data with the video on the simulator's centre display. Video output (recorded at 30 Hz) is generated which shows the participant's gaze location and a trail representing a 500 ms gaze trail leading up to the gaze location. Using this video output, the first time the gaze marker intersected with the image of the lead vehicle on the centre screen was identified, and then video was reversed frame-by-frame until the beginning of the continuous movement was found.

As defined in Table 2, the movement toward the event is included as part of the inspection time to be consistent with the ISO definition of a glance: the fixation time plus the transition time (ISO Standard 16673:2007). If the first eye movement toward the braking event could not be determined due to poor gaze quality, then perception time for that event was treated as a missing value. If the participant’s gaze was already on the lead vehicle when its brake lights came on, then the perception time was set to zero and the inspection time was calculated from this event onset. Prior to the experimental drives, participants were asked to look at specific regions on the simulator start screen to help correct for eye glance offsets in post processing.

Table 2: Driving performance metrics and definitions

Driving Performance Metric	**Definition**	**Unit**
Gap time	Gap time between the lead vehicle and the participant's vehicle at the start of the lead vehicle braking event	seconds
Perception time (PT)	Lead vehicle braking event onset to start of first eye movement towards lead vehicle after onset	milliseconds
Inspection time (IT)	Start of first eye movement toward lead vehicle after lead vehicle braking onset until the accelerator completely released	milliseconds
Response time until accelerator completely released (ART)	Time from the event onset until the foot (initially on the accelerator pedal) is no longer in contact with the accelerator pedal or when the accelerator position signal reaches zero	milliseconds
Brake transition time (BTT)	Time from accelerator pedal release to brake pedal contact	milliseconds
Response time until brake contacted (BRT)	ART + BTT	milliseconds
Minimum time to collision (TTC_{min})	The shortest time-to-collision with the lead vehicle during a braking event where time to collision is defined by Hayward (1972): "The time required for two vehicles to collide if they continue at their present speed and on the same path"	seconds
Maximum deceleration	The maximum deceleration of a participant in a region of interest. Must be less than zero.	m/s^2
Average gap accepted	The average of gap times between the two vehicles participants chose to make a left turn through for both left-turn intersections	seconds
Average speed	The average speed of the participant vehicle in a region of interest (Figure 8). An average was calculated from speed samples (collected at 60 Hz)	mph
Speed variability	The standard deviation of the participant vehicle's speed in a region of interest (Figure 8). A standard deviation was calculated from speed samples (collected at 60 Hz)	mph
Standard Deviation Of Lane Position (SDLP)	The standard deviation of the participant vehicle's lane position in a region of interest (Figure 8). A standard deviation was calculated from lateral position relative to lane centre (collected at 60 Hz)	feet
Average absolute deviation from speed limit	The average absolute deviation from the speed limit (50 mph, rural; 35 mph urban). An average was calculated from the absolute difference between the speed limit and participants' speed (collected at 60 Hz)	mph

3.3.3.1 Lead vehicle braking data reduction

As mentioned previously, the participants were told to maintain their speed at 50 mph in the rural region where the lead vehicle braking events occurred, unless the vehicle in front of them was braking. This instruction was used to better control for gap time between the participant's vehicle and the lead vehicle prior to a braking event. However, the participants who failed to maintain speed when the lead vehicle adjusted its speed to theirs and the participants who delayed accelerating to resume speed after the previous braking event could force the creation of a large gap between their vehicle and the lead vehicle. Overall, the experiment had 432 (36 participants x 3 conditions x 4 events per condition) lead vehicle braking events of interest. Of these events, instances were removed if the throttle was already released prior to the event onset (56) or if participants did not brake (12) in response to the lead vehicle braking, most likely due to participants driving at very low speeds. Further, braking events where participants drove on average less than 15 mph (23 cases) under the recommended speed prior to braking (when the lead vehicle was adjusting its speed) were removed. Braking events where participant's gap time was over 6.2 s (2 SDs from the mean gap time of 2.9 s, SD = 1.6) (24 cases) were also removed.

Participants exhibited distraction engagement by tapping or glancing toward the secondary display. The lead vehicle braking event responses under the voluntary distraction condition where the participant chose to not engage in the secondary task are likely different than their responses when they engaged in the task. A linear mixed model using accelerator release time (ART) as the dependent variable and 'condition' as the independent variable was built to investigate this possibility (condition had three levels: baseline, voluntary distraction drive with engagement, voluntary distraction drive without engagement). A logarithmic transform was used on the dependent variable to meet normality assumptions, gap time was used as a covariate, and participant was modeled as a random factor.

Condition was significantly related to ART (F(2, 169) = 3.61, *p* = .03). Planned contrasts showed that ART was significantly longer for participants interacting with the secondary display under voluntary distraction (Δ= 21%, 95% CI: 2, 45, *p* = .03) versus baseline driving. However, ARTs for participants who did not engage under voluntary distraction were not significantly different from baseline (*p* = .98), nor from those of participants engaging under voluntary distraction (*p* = .20). Thus, since the properties of non-engagement ARTs were not consistent with those of engagement ARTs, the non-engagement cases were excluded from later analysis (22 events). All involuntary distraction observations were retained because, even if participants did not glance toward the involuntary distraction during the braking event, they may have engaged with the auditory component of the involuntary distraction stimulus.

The remaining 295 braking events used for analysis included 111 baseline events, 74 voluntary distraction events with distraction engagement, and 110 involuntary distraction events. These events were aggregated (averaged) to the level of distraction type x road curvature (straight or curved road) resulting in N= 186 data points each for ART, BRT, BTT, and maximum deceleration analysis. Out of these 295 eligible events, one more event was removed for TTC_{min} analysis due to missing TTC_{min} data, resulting in N = 186 when aggregated to the level of distraction x road curvature.

Out of the 295 eligible events reported above, 131 were removed for the perception time analysis since the participant’s gaze was already on the lead vehicle when the event started. These events were aggregated to the level of distraction type x road curvature, resulting in N = 164. For inspection time analysis, out of the 295 eligible events reported above, 28 were removed because the throttle was released before the inspection time period started. These events were aggregated to the level of distraction x road curvature, resulting in N = 172 for inspection time analysis.

3.3.4 Driving measures for gap acceptance

The average of the two accepted gap times per experimental drive was used as a measure of gap acceptance, N = 108 (Table 2). Prior to this aggregation, seven left-turn gap acceptance events from seven different participants were removed due to the participants either turning prior to the oncoming traffic arriving at the intersection (4 events) or the simulator not rendering the oncoming cars properly: the oncoming vehicles disappeared when the participants arrived at the intersection (3 events). Again prior to this aggregation, a cumulative link mixed model (for ordinal data with repeated measures), fitted with a Laplace approximation (Christensen, 2015) and with participant as a random factor, was used to test if gap acceptance differed within voluntary distraction condition when participants did or did not engage in the secondary task. The only gaps accepted by participants were 4 s, 5 s, 6 s, and 7 s, and hence the dependent variable (gap accepted) was ordinal. The analysis found that ‘condition’ (levels: baseline, voluntary distraction with engagement, and voluntary distraction without engagement) was not significantly related to gap size accepted ($\chi^2(2) = 2.02$, $p = .36$). Thus, no further data were removed.

3.3.5 Driving measures in non-braking-event driving

Three non-braking-event sections, where an irrelevant stimulus occurred during the involuntary distraction condition, were selected to examine driving performance without the presence of an event that required braking (Figure 8). Data from these regions were used to examine changes in standard deviation of lane position (SDLP), average speed, and speed variability across the three experimental conditions (Table 2). These regions were different sizes: region 1 was 2392 ft (32.6 seconds when driving 50 mph); region 2 was 851 ft (16.6 seconds when driving 35 mph); and region 3 was 1026 ft (20.0 seconds when driving 35 mph). For analysis, driving performance data of the three regions were not aggregated because region 1 was a rural road, while regions 2 and 3 were urban roads, and because region 2 occurred right after the left-turn gap acceptance task, so drivers may still have been accelerating in that region, while region 3 was not adjacent to any other driving event.

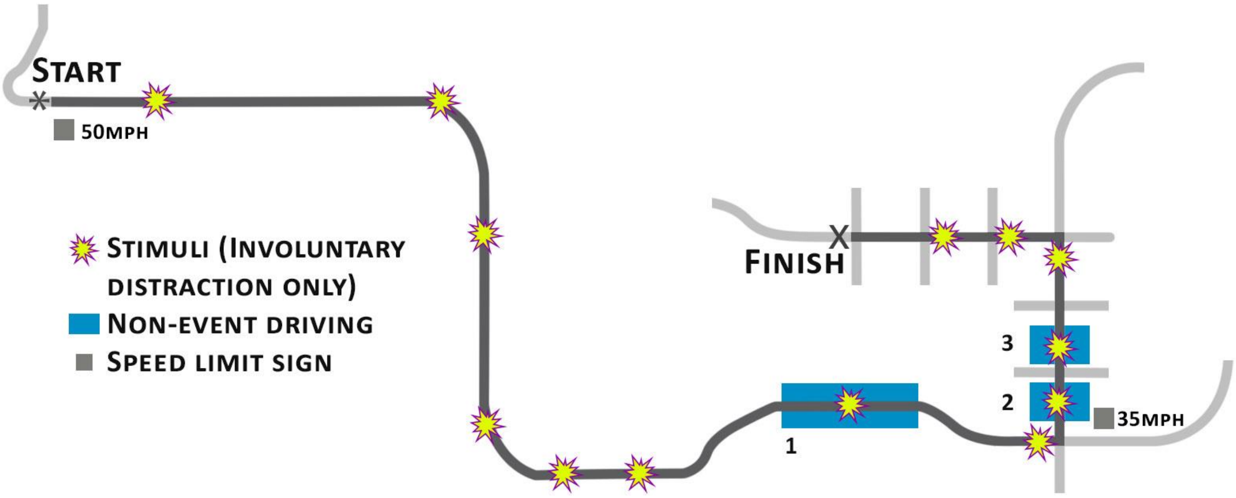


Figure 8: Locations of non-braking-event driving regions 1, 2, and 3 within the simulated drive

As was done for the lead vehicle braking events, driving performance data were analyzed from the voluntary distraction and baseline drives to identify whether the data collected in the voluntary distraction condition where participants did not interact with the secondary task should be included in further analysis. In this case, the chosen driving metric (and dependent variable) was average speed. This metric was chosen because it was expected that the voluntary distraction task would have an effect on speed, since lower speed maintenance under this distraction task has been observed previously (Donmez et al., 2007). A linear mixed model was used with region and 'condition' (baseline, voluntary with engagement, voluntary without engagement) as fixed factors and participant as a random factor.

There was a significant relationship between condition and average speed (F(2, 176) = 7.95, *p* = .0005). Planned contrasts showed a significant difference between average speed for participants who engaged with the secondary task and the baseline condition (Δ = -1.60 mph, 95% CI: -2.56, -0.63 *p* = .0001), and a significant difference between participants who engaged and participants who did not engage in the voluntary distraction (Δ = -2.07 mph, 95% CI: -3.94, -0.19 *p* = .01). However, there was no significant difference between participants who did not engage and the baseline condition (*p* = .53). Region also had a significant effect (F(2, 176) = 681.3, *p* < .0001). Given these differences, 22 observations from the voluntary distraction condition where participants did not engage with the secondary task were removed. After reduction, the analysis for average speed, speed variability, and SDLP used 302 data points.

All involuntary distraction observations were retained because, even if participants did not glance toward the involuntary distraction during the braking event, they may have engaged with the auditory component of the involuntary distraction stimulus.

3.4 Hypotheses

Both engagement and driving performance were used to indirectly measure driver distraction.

3.4.1 Self-reported distraction engagement and distraction engagement in simulated driving

It was expected that individuals who self-reported greater susceptibility to engagement with secondary tasks while driving (SRDE) would engage more, and longer, with the voluntary distraction task.

It was also expected that participants who self-reported greater susceptibility to involuntary distraction would engage more, and longer, with the irrelevant stimuli under the involuntary distraction condition.

3.4.2 Driving performance under distraction

Longer response times to braking events were expected under voluntary distraction than both the baseline and involuntary distraction conditions. It was expected that response times observed under involuntary distraction would be longer than in baseline driving, but shorter than those under voluntary distraction. Delays in response time could lead to shorter TTC_{min} and larger maximum deceleration.

It was also expected that drivers under voluntary distraction may make poorer tactical driving decisions exhibited through smaller gap selection during the left-turn gap acceptance events since poorer decision making has been observed previously under secondary, although non-self-paced (externally paced), tasks (Cooper & Zheng, 2002; Cooper et al., 2003).

In the non-braking-event driving regions, it was expected that under voluntary distraction, participants would drive slower and have larger SDLPs as have been observed under other secondary, although not self-paced, distraction tasks (Caird et al., 2014).

It was expected that under involuntary distraction participants may also drive slower as drivers have previously been observed driving slower around video advertisements (Chattington et al., 2009), which can be a form of involuntary distraction.

Regan et al. (2011) in their review reason that while engaging in voluntary distraction activities, drivers are potentially able to “*compensate for the anticipated act of this diversion on their driving performance*”, whereas involuntary distraction does not allow for self-regulation, and that “*the psychological mechanisms involved in these two scenarios may be quite different, and may lead to different patterns of interference*”. Similarly, Sheridan (2004) argues that the effects of involuntary and voluntary distraction may not vary unless voluntary attention is different because it has a planned aspect. Thus, it was hypothesized that driving performance metrics may be less affected under voluntary distraction during expected events (i.e., left-turn gap acceptance) than during unexpected events.

3.5 Results

3.5.1 Self-reported distraction engagement and distraction engagement in simulated driving

3.5.1.1 Voluntary distraction condition

Of the 36 participants, 35 chose to engage with the secondary task. On average, these 36 participants completed 9.17 tasks (SD = 5.26 tasks). It took an average of 61.1 s to complete one task (SD = 93.5 s). Participants on average made 119 glances at the secondary display (SD = 48.8 glances) over the entire drive (M = 10 min and 15 s, SD = 40 s), and these glances averaged at a duration of 1.24 s (SD = 0.4 s). These glance counts correspond to an average of 22.6% of drive time (SD = 10.3%) spent looking at the secondary display. Finally, the average time between tasks (including the time it took for the participant to start their first task) was 19.3 s (SD = 213 s). Participants tapped the secondary display 95.8 times on average (SD = 71.4 taps) to interact with the secondary task.

Three generalized linear models with log link function and quasi-Poisson distribution were used to determine if a relationship existed between participants' SRDE groups and number of glances, number of taps, and number of tasks completed. As these numbers may be influenced by total drive time, drive time was included as an offset variable. There was a significant relationship between the number of glances and SRDE ($\chi^2(2) = 228.0$, $p = .009$) (Figures 9 and 10). Participants in the high SRDE group had a glance rate that was 70% more than those in the low group (95% CI: 10, 162, $p = .01$) and a marginally significant 49% more than those in the medium group (95% CI: -2, 127, $p = .07$). There was no significant difference between the medium and low groups ($p = .79$). There was no significant relationship between the number of taps on the Surface Pro 2 and SRDE ($\chi^2(2) = 141.5$, $p = .26$). There was a marginally significant relationship between number of tasks completed and SRDE ($\chi^2(2) = 15.8$, $p = .06$) with the high SRDE group having a task completion rate that was 70% more than the low group (95% CI: -1, 190, $p = .05$), but with no significant difference between medium and low ($p = .66$), nor high and medium groups ($p = .31$).

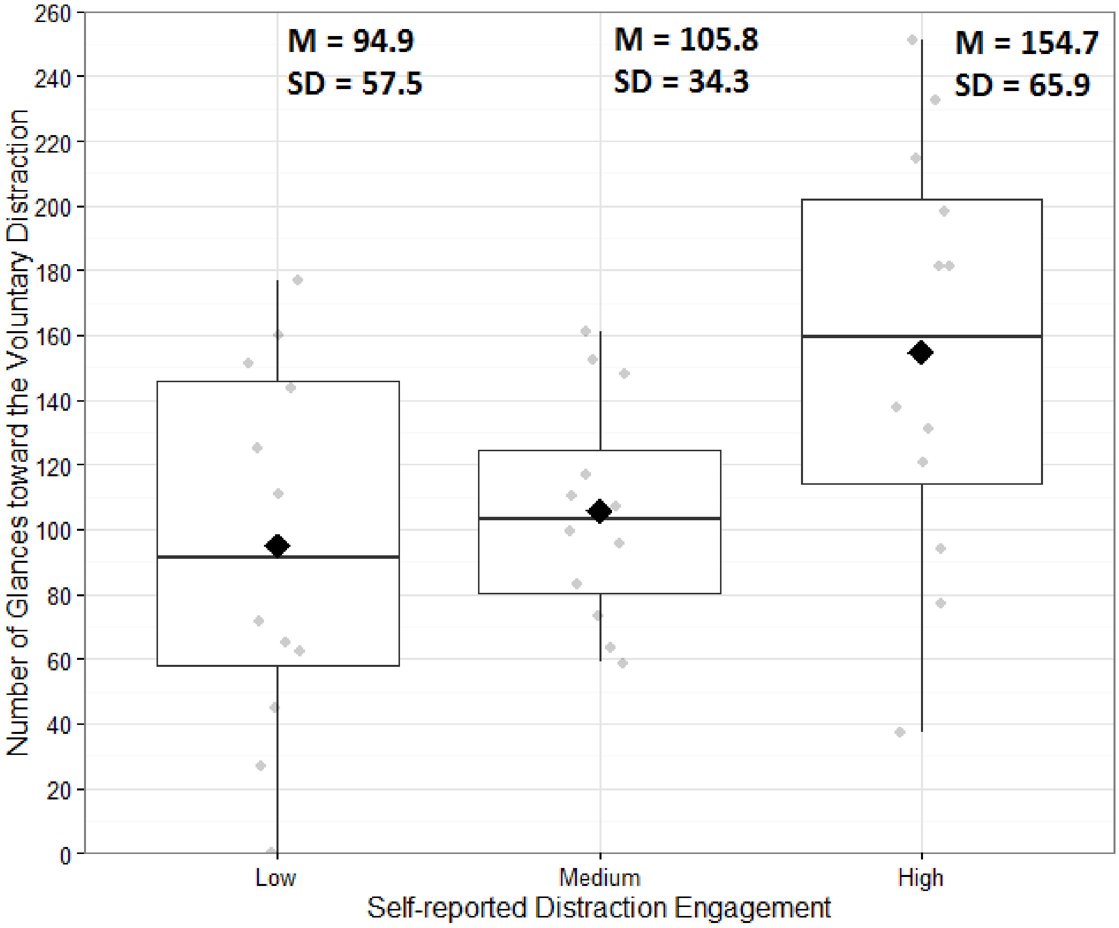


Figure 9: Boxplots of the number of glances participants made toward the secondary task throughout the entire voluntary distraction drive with respect to their SRDE group

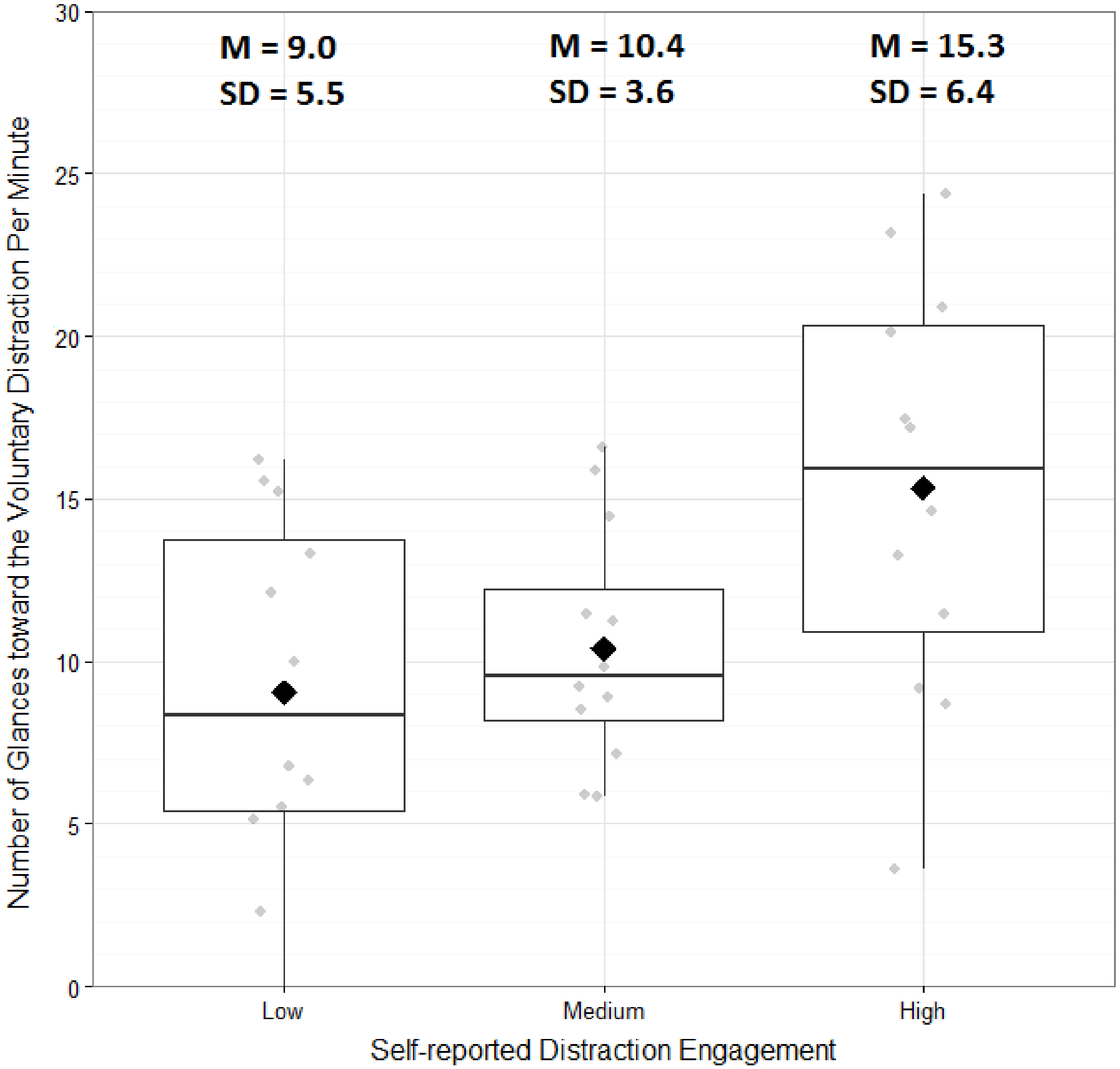


Figure 10: Boxplots of participants' glance rates (glances per minute) toward the secondary task throughout the entire voluntary distraction drive with respect to their SRDE group

A linear regression model, with a logarithmic transform on the dependent variable to meet modelling assumptions, found no significant relationship between participants' SRDE and their average glance durations (F(2, 32) = 0.83, *p* = .44). The same type of models were used to relate the logarithmic transform of average time between tasks to SRDE group (F(2, 32) = 0.85, *p* = .44), and the logarithmic transform of average task time to SRDE group (F(2, 32) = 1.50, *p* = .24), but no significant relationships were found. The number of glances of high and low SRDE groups were compared using an independent t-test for glances over 1600 ms and an exact

Wilcoxon test (used to account for ties) for glances over 2000 ms. These values were of interest as glances over 1600 ms have been found to affect driving performance (Bischoff, 2007), and glances away from the road over 2000 ms can double the risk of crashes (Dingus et al., 2006) and are generally considered dangerous in the driving literature. These analyses found no significant differences among the self-reported engagement groups for glances over 1600ms (t(22) = -0.65, *p* = .52), nor for glances over 2000ms (W = 69.5, *p* = .90).

3.5.1.2 Involuntary distraction condition

Out of the 36 participants, 32 glanced at least once at the secondary display at the irrelevant stimuli in the involuntary distraction condition. Overall, these 36 participants glanced an average 5.22 times at the stimuli (SD = 5.46) (Figure 11a) with each glance being on average 548 ms (SD = 207 ms) (Figure 11b). Only one participant had a glance over 2 seconds toward the involuntary distraction, so further analysis was not performed on participants' longer glances. It took the participants 1329 ms (SD = 929 ms), on average, to look at the stimulus after the stimulus' onset (glance initiation time). In this experiment, there were 0.47 glances per subject per stimulus and overall participants glanced toward 36% of all stimuli presented (143 of 396).

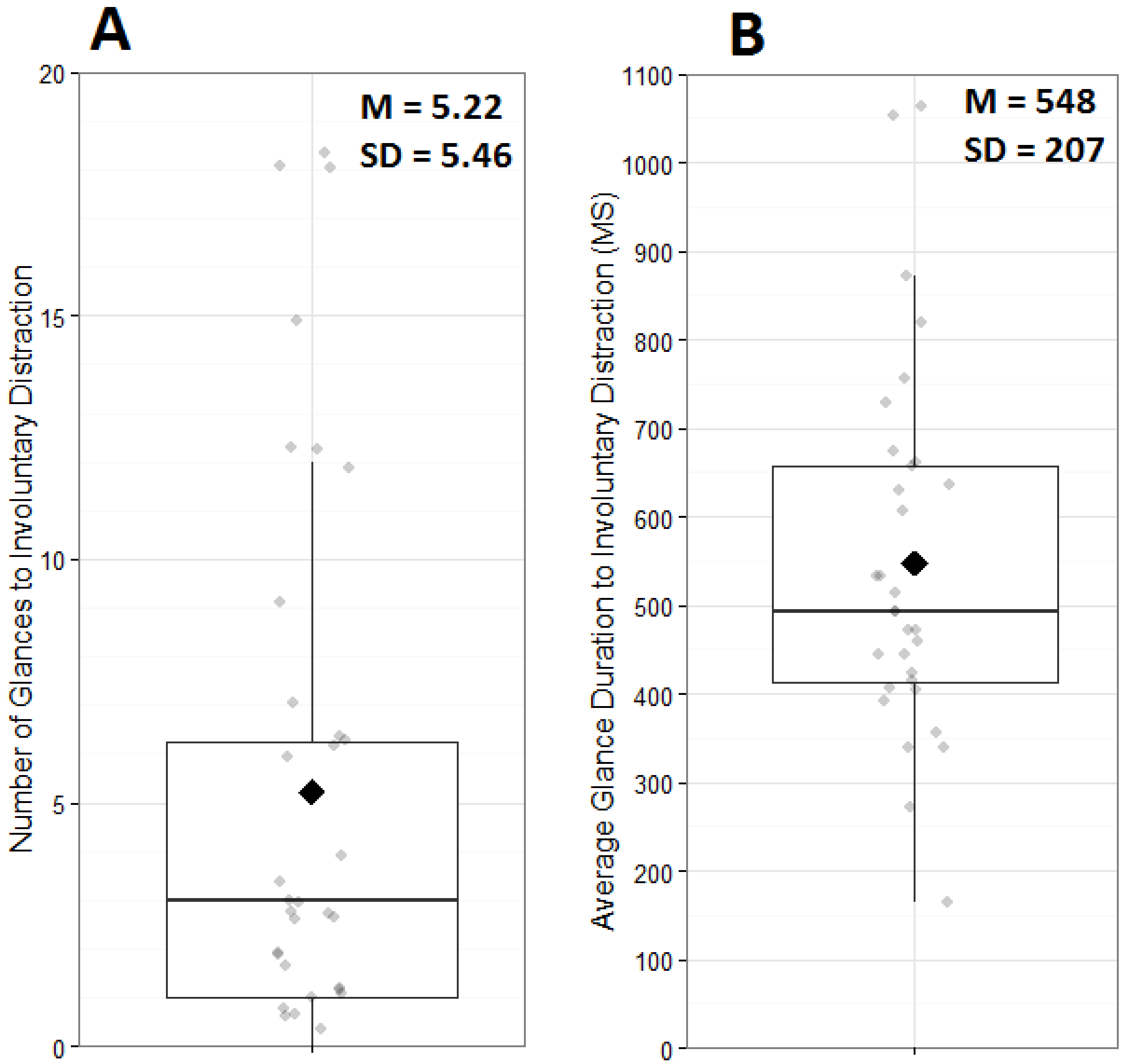


Figure 11: Boxplots of (A) participants' number of glances and (B) the average duration of glances participants made toward the involuntary distraction

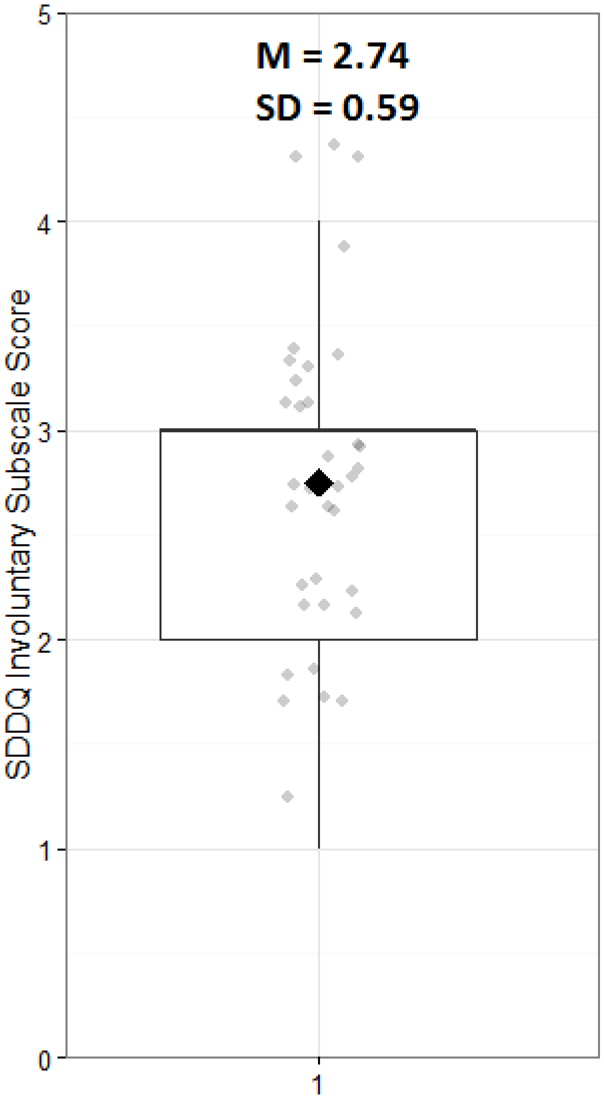


Figure 12: Boxplot of the participants' self-reported SDDQ involuntary subscale scores for measuring susceptibility to involuntary distraction

Individual differences (variance in responses) were observed both in participants' engagement with the involuntary distraction (Figure 11) and in their self-reported susceptibility to involuntary distraction (Figure 12). However, the SDDQ involuntary subscale is not useful for measuring susceptibility to irrelevant stimuli in simulated driving as SDDQ scores were not related to engagement with the involuntary stimuli. A generalized linear model with a log link function and a quasi-Poisson distribution with number of glances as the dependent variable did not find a relationship between participants' number of glances toward the irrelevant stimuli in the involuntary distraction condition and their score on the SDDQ Involuntary distraction subscale ($\chi^2(1) = 12.7$, $p = .14$). Linear regression models with logarithmic transforms on the dependent variables were used to relate involuntary distraction glance metrics to the SDDQ involuntary distraction subscale. Average glance duration was related to the involuntary distraction subscale (F(1, 30) = 5.61, *p* = .02), except that an increase in involuntary distraction score (indicating greater self-reported distractibility) was associated with 24% shorter average glance durations (95% C: 4, 39). Glance initiation time was not related to the involuntary distraction subscale (F(1, 30) = 0.99, *p* = .33).

Further analysis using a generalized linear model with a log link function and a quasi-Poisson distribution showed that number of glances to the irrelevant stimuli was also not related to SRDE group ($\chi^2(2) = 6.96$, *p* = .55), indicating that participants were not interacting with the involuntary distraction in the same way they were interacting with the voluntary distraction.

3.5.1.3 Self-reported distraction engagement and distraction engagement during simulated driving for different driving scenarios

As mentioned previously, there is evidence that drivers are not always strategic in how they engage in distractions, as shown by Horrey and Lesch (2009). Since the voluntary distraction secondary task was self-paced, it was of interest to see if certain SRDE groups differed in their distraction engagement behaviour during the different driving scenarios discussed below: lead vehicle braking events, left-turn gap acceptance events, and non-braking-event driving. Relevant analyses are presented below for each driving scenario.

3.5.2 Lead vehicle braking events

As mentioned previously, due to participants not engaging with the secondary task during the lead vehicle braking events, 22 individual events were removed from further braking response analysis. Analysis was performed to determine if a disproportionate number of event samples were removed from one SRDE group (SRDE groups: 7 low, 10 medium, 5 high). If there was a disproportionate removal, it would not be useful to compare driving metrics across SRDE groups since the stronger non-interaction attribute of one group would be disregarded. A generalized linear mixed model fit by maximum likelihood (Laplace Approximation) using a binomial (logit) distribution with participant as a random factor was used to ascertain if there was a disproportionate removal. All eligible braking event responses under voluntary distraction were used (including when the driver did not interact with the secondary task). No relation was found between SRDE group and whether or not participants chose to interact with the secondary task during lead vehicle braking events ($\chi^2(2) = 3.14$, *p* = .21). Thus, since the removed samples did not disproportionally belong to one SRDE group, all lead vehicle braking event models used SRDE and distraction type as explanatory variables. Self-reported distraction engagement and distraction engagement during lead vehicle braking events.

Voluntary distraction engagement metrics (number of taps and number of glances) were summed across all four braking events. The distraction engagement metrics were sampled both prior to, and after lead vehicle braking onset: starting at the moment the lead vehicle began controlling for gap time with the participants' vehicle, on average 12.6 s (SD = 1.6 s) prior to lead vehicle braking onset (Figure 6), until the lead vehicle stopped braking (7 s after braking onset). The time during these intervals was also summed across all four braking events to obtain the lead vehicle braking event time variable (36 total data points with 1 data point per participant).

Generalized linear models using a quasi-Poisson distribution and a log link function with the lead vehicle braking event time as an offset variable were built to compare the number of times participants in the high, medium, and low SRDE groups glanced toward, and tapped on, the secondary display under voluntary distraction. Glance rates were significantly related to SRDE ($\chi^2(2) = 58.6$, $p = .002$). The high SRDE group had glance rates that were 80% more than the low group (95% CI: 19, 170, $p = .005$) (Figure 13). The rate of taps were marginally related to SRDE ($\chi^2(2) = 28.2$, $p = .08$). The high SRDE group had a tap rate that was marginally 85% more than the low group (95% CI: 0, 236, $p = .05$). Thus, the glance rate toward the voluntary distraction results for braking events were similar to those observed in the overall drive. Unlike during the overall drive, where tap rate was not significantly related to SRDE, during the lead vehicle braking events, the high SRDE group had a marginally greater tap rate than the low SRDE group.

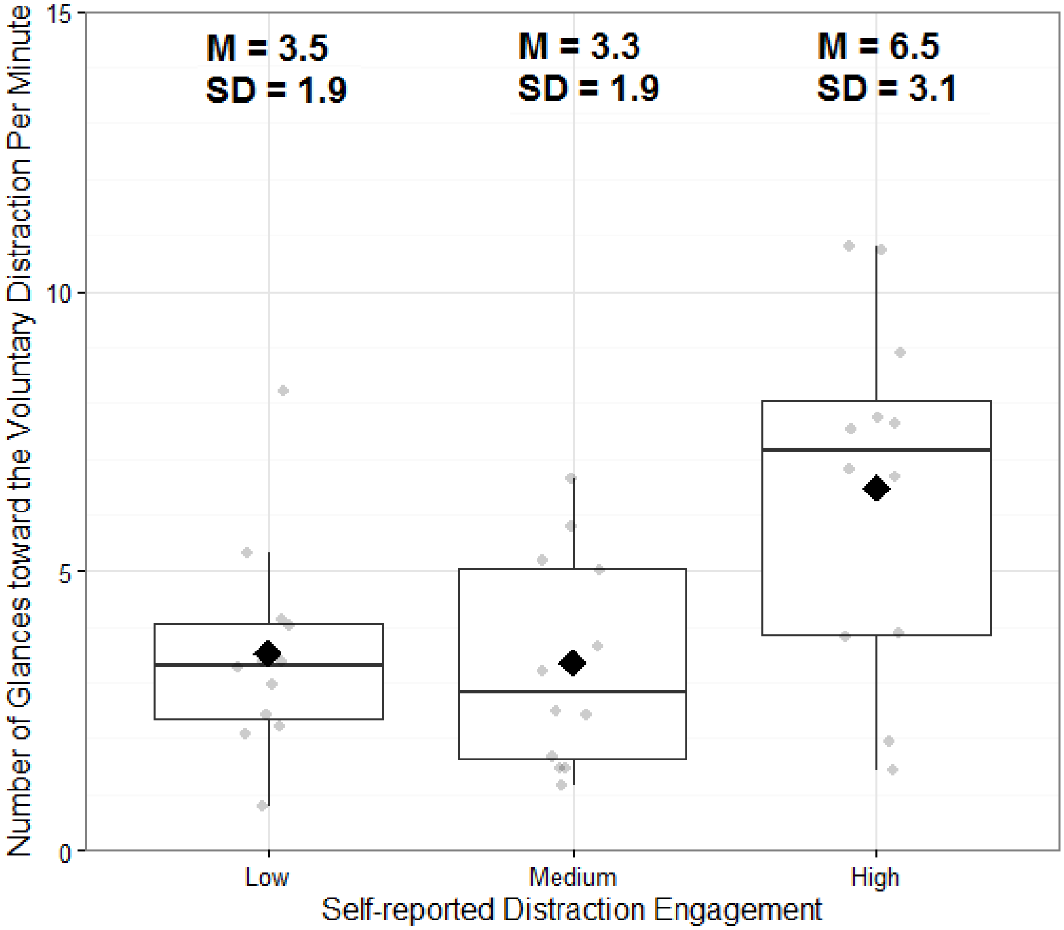


Figure 13: Boxplots of participants' glance rates (glances per minute) toward the secondary task throughout the lead vehicle braking events with respect to their SRDE group

3.5.2.1 Gap and response times

Linear mixed models were used to analyze the vehicle braking event metrics defined earlier in Table 2. Descriptive statistics for these driving metrics can be found in Appendix H. All of the dependent variables used logarithmic transforms to meet normality assumptions. The independent variables were distraction type and SRDE. Participant was treated as a random factor. Road curvature (straight versus curved road), gap time at the lead vehicle brake onset, and their interactions with the other factors were used as covariates. Non-significant interactions were removed from the final models. Table 3 provides a summary of the F-statistics for the final models. Planned contrasts in post-hoc analysis were used to assess the differences in the dependent variables between categorical variable levels.

It should be noted that gap time differed based on distraction type (F(2, 147) = 9.40, *p* = .0001) (ascertained using a linear mixed model). Planned contrasts showed that gap times were 18% longer under voluntary distraction than in baseline driving (95% CI: 7, 29, *p* = .0003), and 18% longer under voluntary distraction than under involuntary distraction (95% CI: 7, 30, *p* = .0003). However, there was no significant difference between gap times under involuntary distraction and in baseline driving (*p* = .99). There was also no relationship between road curvature and gap time (F(1,147) = 1.68, *p* = .20).

Table 3: Lead vehicle braking event statistical modeling results. More detailed results showing removed interaction terms can be found in Appendix I

	Gap time		Road curvature		Distraction		SRDE		SRDE * Gap time		Road curvature * Gap time	
Response variable	F-value	*p*	F-value	*p*	F-value	*p*	F-value	*p*	F-value	*p*	F-value	*p*
ART	F(1,146) = 5.89	.02	F(1,146) = 1.01	.32	F(2,146) = 5.15	.007	F(2,33) = 1.08	.35	--	--	--	--
BTT	F(1,146) = 6.06	.02	F(1,146) = 11.41	.0009	F(2,146) = 3.02	.05	F(2,146) = 0.24	.79	--	--	--	--
BRT	F(1,146) = 9.93	.002	F(1,146) = 11.47	.0009	F(2,146) = 1.77	.17	F(2,33) = 0.24	.79	--	--	--	--
Maximum deceleration	F(1,144) = 0.84	.36	F(1,144) = 0.01	.91	F(2,144) = 0.30	.74	F(2,33) = 1.41	.26	F(2,144)= 3.34	.04	--	--
TTC_{min}	F(1,146) = 0.04	.84	F(1,146) = 37.18	<.0001	F(2,146) = 3.55	.03	F(2,33) = 0.49	.62	--	--	--	--
PT	F(1,92) = 8.45	.005	F(1,92) = 3.28	.07	F(1,92) = 2.14	.12	F(2,32) = 1.16	.33	--	--	--	--
IT	F(1,132) = 18.27	<.0001	F(1,132) = 1.96	.16	F(2,132) = 8.02	.0005	F(2,32) = 0.06	.95	--	--	F(1,132) = 7.35	.008

Participants showed delayed ARTs in the lead vehicle braking events under involuntary and voluntary distraction (Figure 14). Participants were 19% slower to release the accelerator pedal (on average) in response to lead vehicle braking under involuntary distraction (95% CI: 3, 39, *p*

= .02) and 23% slower under voluntary distraction (95% CI: 4, 46, *p* = .01). These delays under voluntary and involuntary distraction were not significantly different (*p* = .91).

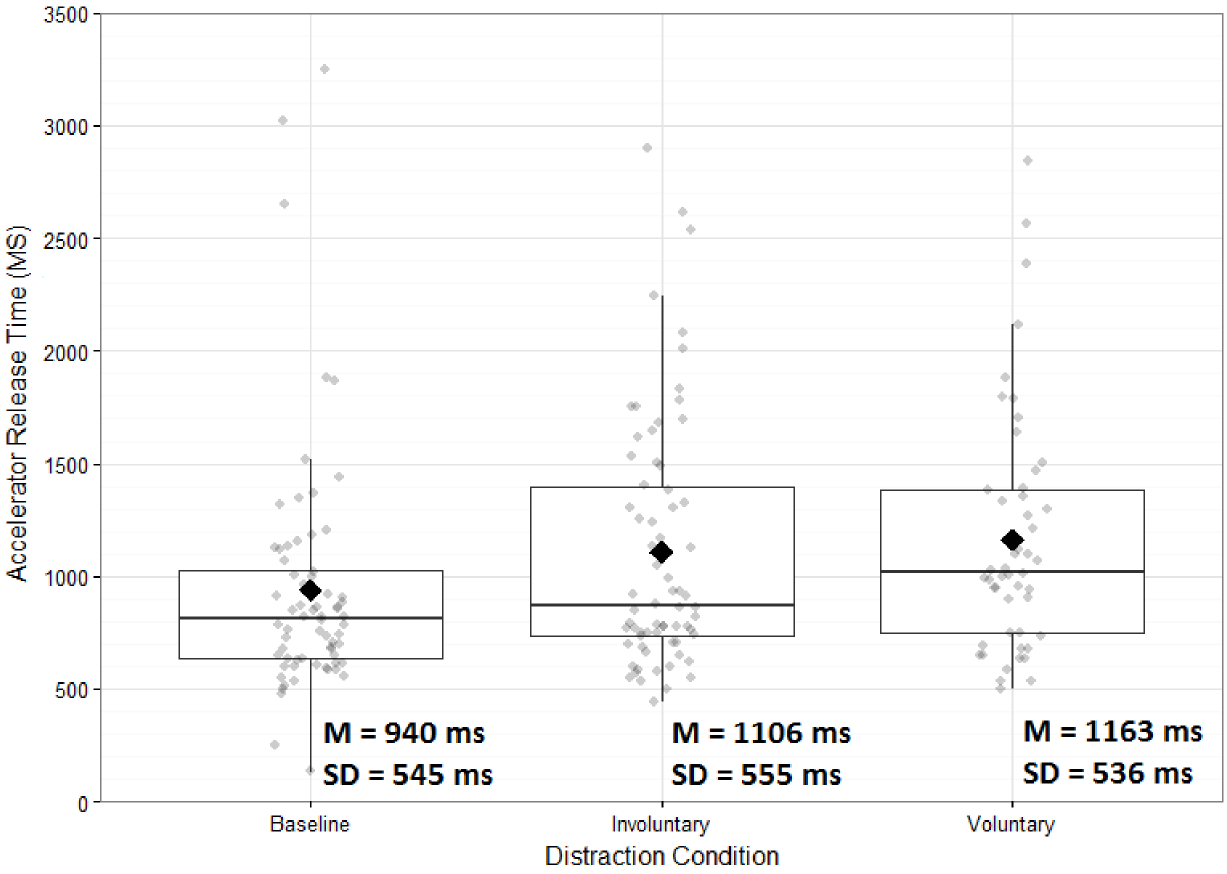


Figure 14: Boxplots of participants' average ARTs in Experiment 1

Participants had marginally shorter BTTs under voluntary distraction (Δ=14%, 95% CI: -1, 27, *p* = .06, Figure 15) compared to the baseline condition, but there was no significant difference between BTTs under involuntary distraction and in baseline driving (*p* = .99). Despite the accelerator release delays, but possibly due to the marginally shorter BTTs under voluntary distraction, participants' BRTs were not significantly related to distraction type (*p* = .17).

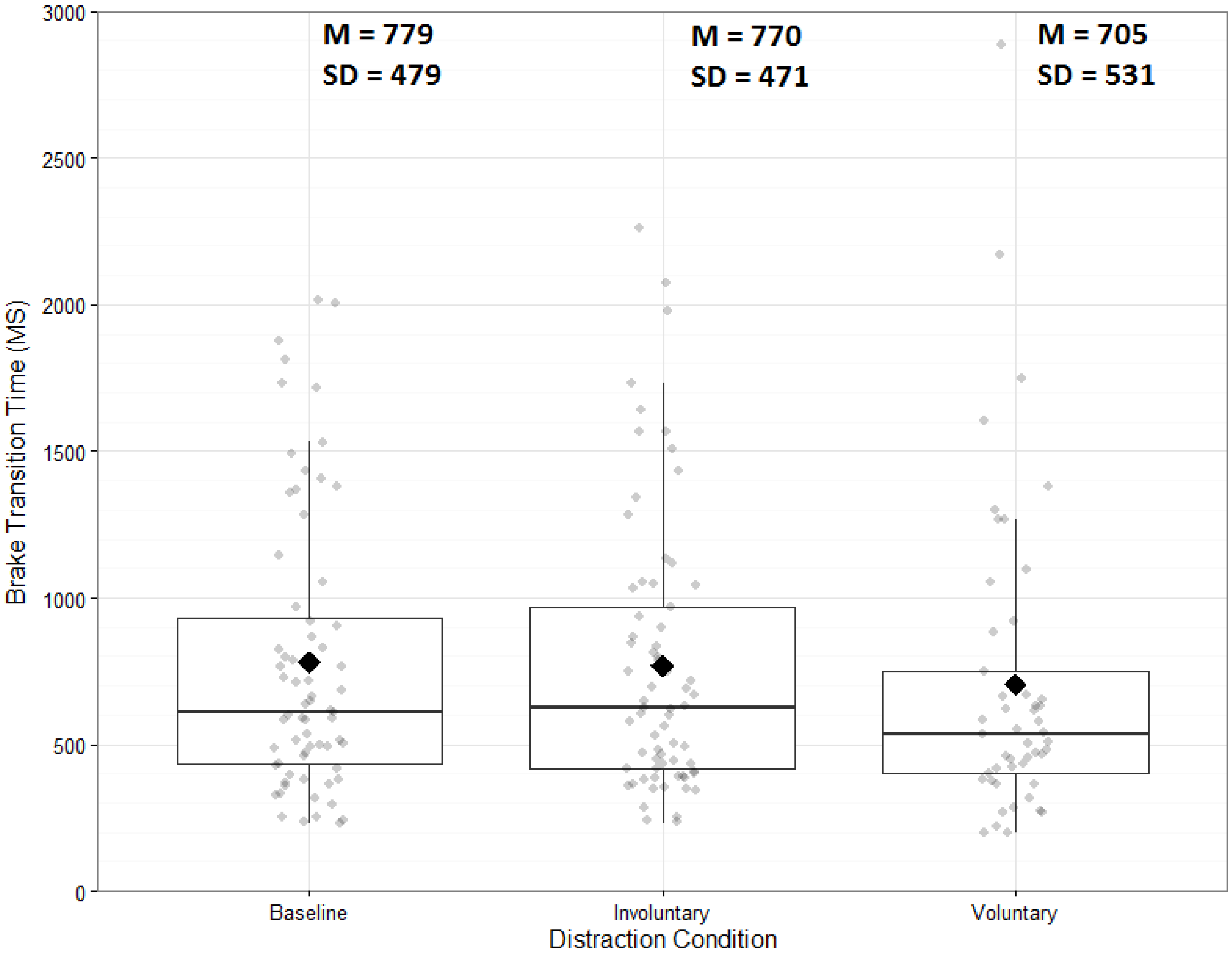


Figure 15: Boxplots of participants' average BTTs in Experiment 1

3.5.2.2 Perception and inspection times

There was no distraction effect on perception times (i.e., PTs, *p* = .12). Participants' ITs were 30% longer under involuntary distraction (95% CI: 11, 54, *p* = .0008, Figure 16). However, there was no significant difference between voluntary distraction and baseline ITs (*p* = .99).

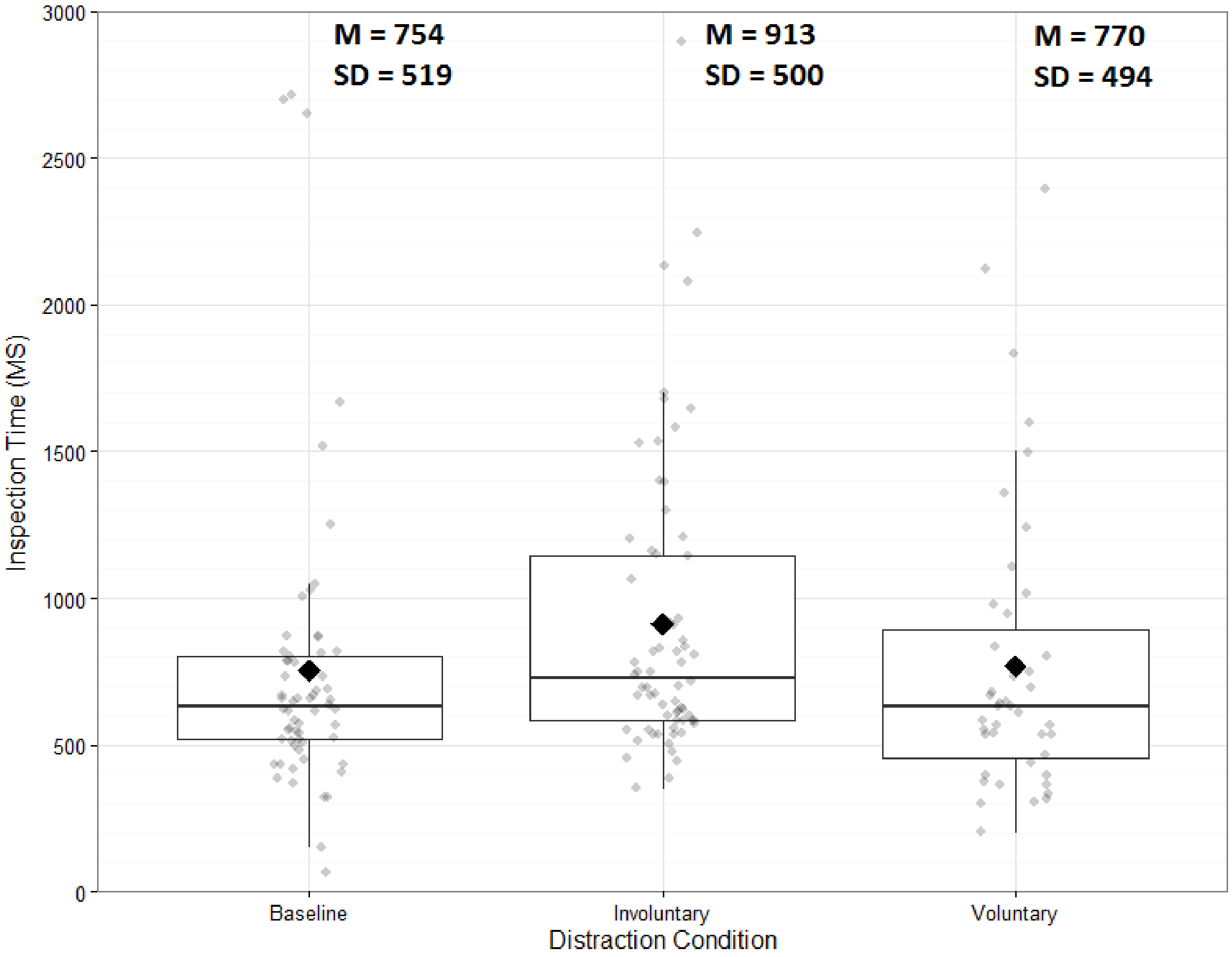


Figure 16: Boxplots of participants' average ITs in Experiment 1

3.5.2.3 Minimum time to collision and maximum deceleration

Under involuntary distraction, participants had 12% shorter TTC_{min} (95% CI: 1, 21, *p* = .04, Figure 17); however, there were no differences in TTC_{min} under voluntary distraction and in baseline driving (*p* = .98). Maximum deceleration was not related to distraction type (*p* = .74). However, participants' maximum deceleration was related to the interaction between their SRDE group and their gap time at the start of the lead vehicle braking event (*p* = .04). For high SRDE drivers, every one second increase in gap time at the lead vehicle brake onset was associated with 12% less maximum deceleration (95% CI: 5, 18, *p* = .0002), but for low SRDE drivers, there was no effect of gap time (*p* = .59).

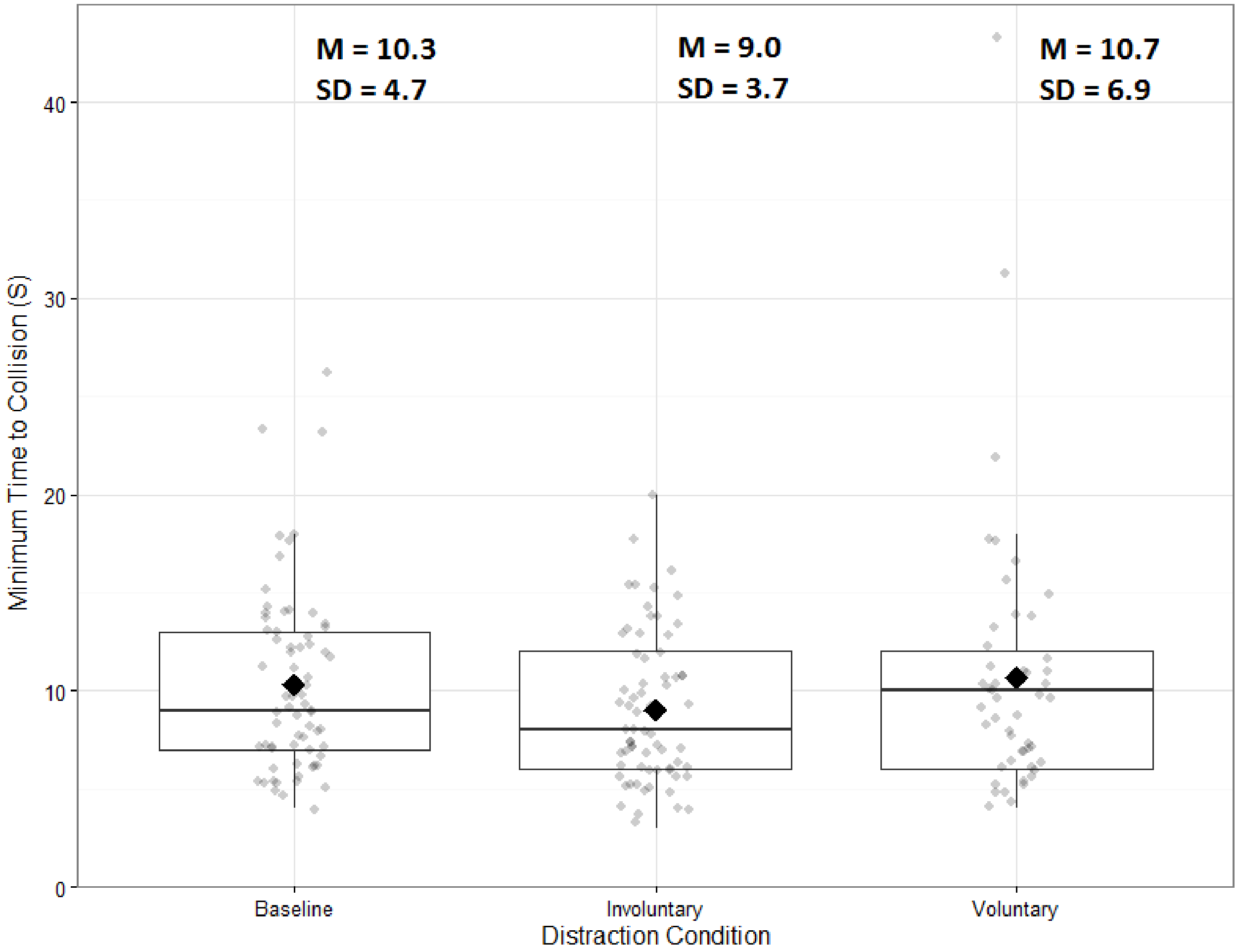


Figure 17: Boxplots of participants' average $\mathrm{TTC}_{\mathrm{min}}$ in Experiment 1

3.5.3 Left-turn gap acceptance

The distraction engagement metrics were summed across both left-turn gap acceptance events. The event time for each gap acceptance event started when the participant arrived at the intersection and finished when they completed turning left onto the intersecting road and drove over the destination road's stop line. Generalized linear models with a quasi-Poisson distribution and log link function, using the summed left-turn gap acceptance event times as an offset variable, found no differences between SRDE levels for rate of glances to the secondary task ($\chi^2(2) = 9.14$, $p = .34$, Figures 18 and 19) nor for rate of taps ($\chi^2(2) = 1.53$, $p = .88$). A linear regression model with a logarithmic transform also did not find any differences in average glance duration between SRDE levels ($F(2, 32) = 0.83$, $p = .44$). Overall, SRDE groups did not exhibit significant differences in the amount they engaged with the secondary task during the gap acceptance events.

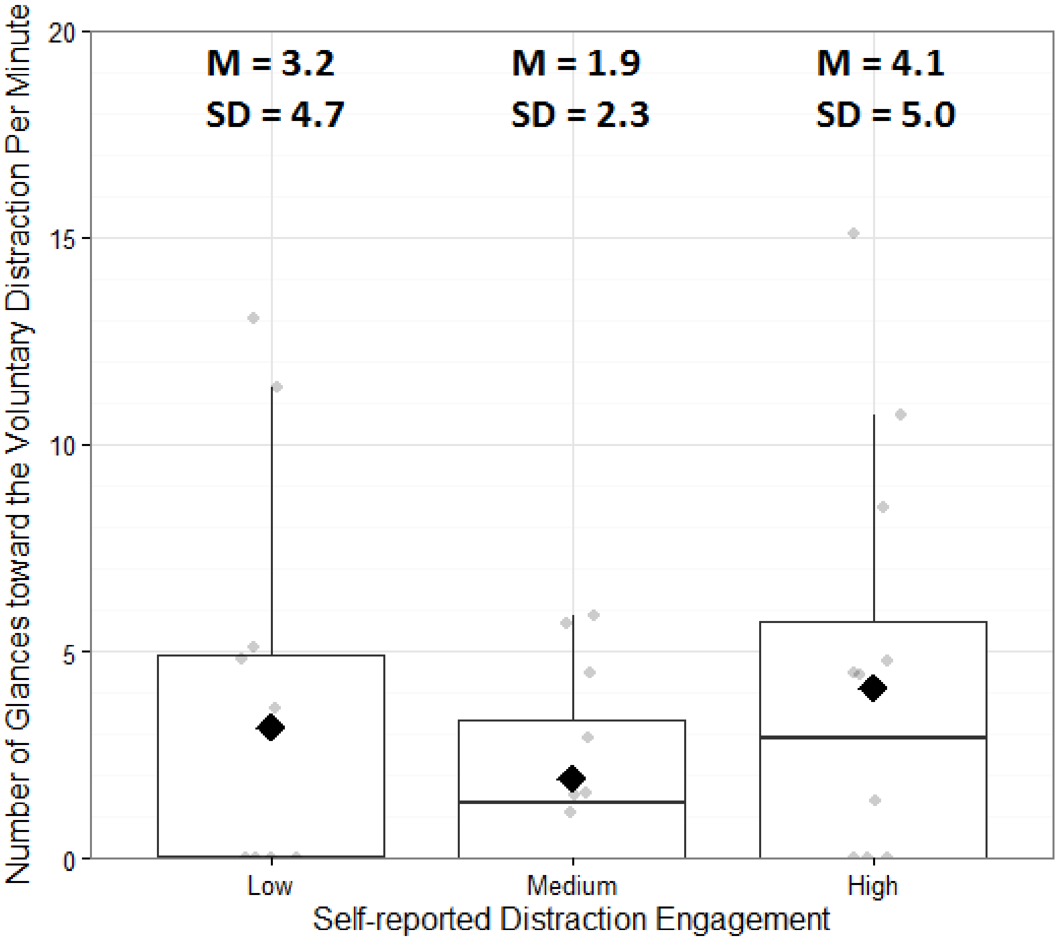


Figure 18: Boxplots of number of glances per a minute toward the voluntary distraction during the left-turn gap acceptance events across SRDE levels

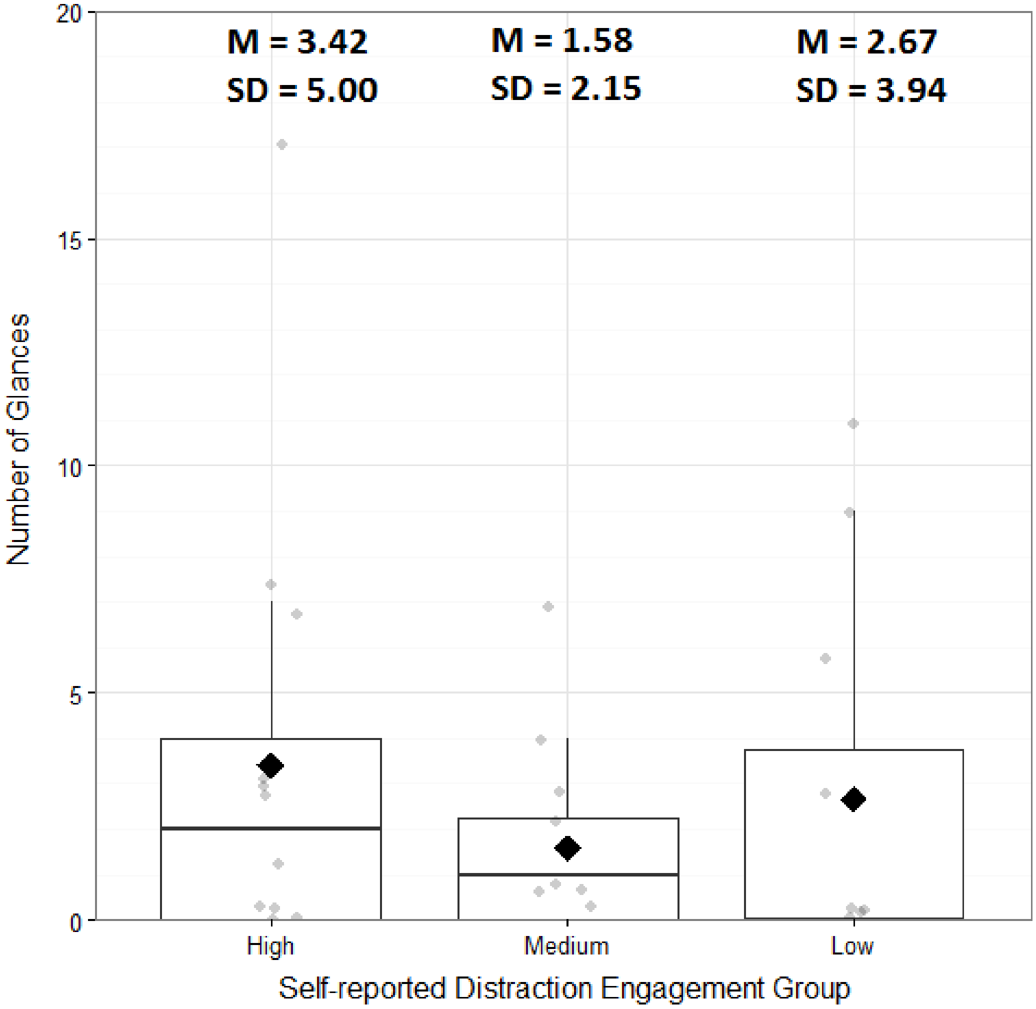


Figure 19: Boxplots showing the number glances participants made toward the voluntary distraction during the left-turn gap acceptance events across SRDE levels

An ordered logit model was used with average gap accepted as a dependent variable as all data points fell into one of five values: 5 s (n = 4), 5.5 s (n = 8), 6 s (n = 61), 6.5 s (n = 15), 7 s (n = 20). Average gap accepted was not related to either independent variable: distraction type ($\chi^2(2) = 1.00$, $p = .61$), SRDE ($\chi^2(2) = 1.13$, $p = .57$). These similarities are also apparent from the descriptive statistics under voluntary distraction ($\bar{x} = 6.17$, SD = 0.45), under involuntary distraction ($\bar{x} = 6.15$, SD = 0.55), and in baseline driving ($\bar{x} = 6.22$, SD = 0.50).

3.5.4 Non-braking-event driving

Due to participants not engaging with the secondary task during some of the non-braking-event driving sections of interest (Figure 8), 22 observations were removed from the non-braking-event driving analysis (SRDE groups: 16 low, 3 high, 3 medium). Analysis was performed to determine if a disproportionate number of observations were removed from different SRDE groups. It would not be useful to compare driving metrics across SRDE groups after a disproportionate removal of observations from one group, since the tendency of one group to not interact would be disregarded. A binomial generalized linear mixed model fit by maximum likelihood, with region and SRDE as independent factors, whether or not participants interacted with the secondary task as the dependent variable, and participant as a random factor, determined that there was an imbalanced removal of observations from one SRDE group ($\chi^2(2) = 7.08$, $p = .03$). A disproportionate number of removed observations belonged to the low SRDE group compared to the high ($p = .04$) and medium groups ($p = .04$). Thus two models were built for each driving performance metric reported below. One model had distraction type as an independent variable and the data set did not include any voluntary distraction observations where participants did not engage in the task. The second model had SRDE group as the independent variable and all observations were used.

3.5.4.1 Self-reported distraction engagement and distraction engagement during non-braking-event driving

For the non-braking-event driving, the findings on the relation between SRDE and secondary task engagement was similar to those findings observed for the entire drive. The distraction engagement metrics were summed for regions 1, 2, and 3 (Figure 8). Non-braking-event region driving time was the sum of times that participants spent driving through regions 1, 2, and 3. Generalized linear models with a quasi-Poisson distribution and log link function and the non-braking-event region driving time as an offset variable were built to investigate the rate of secondary task glances and task taps across different SRDE groups. SRDE group had an effect on glance rates ($\chi^2(2) = 36.7$, $p = .01$) with the high SRDE group having glance rates that are 93% more than the low group (95% CI: 20, 208, $p = .006$) (Figure 20). There was a marginally significant relationship between rate of taps and SRDE ($\chi^2(2) = 42.4$, $p = .07$) with the high SRDE group having a tap rate that is 96% times more than the low group (95% CI: -6, 309, $p = .07$).

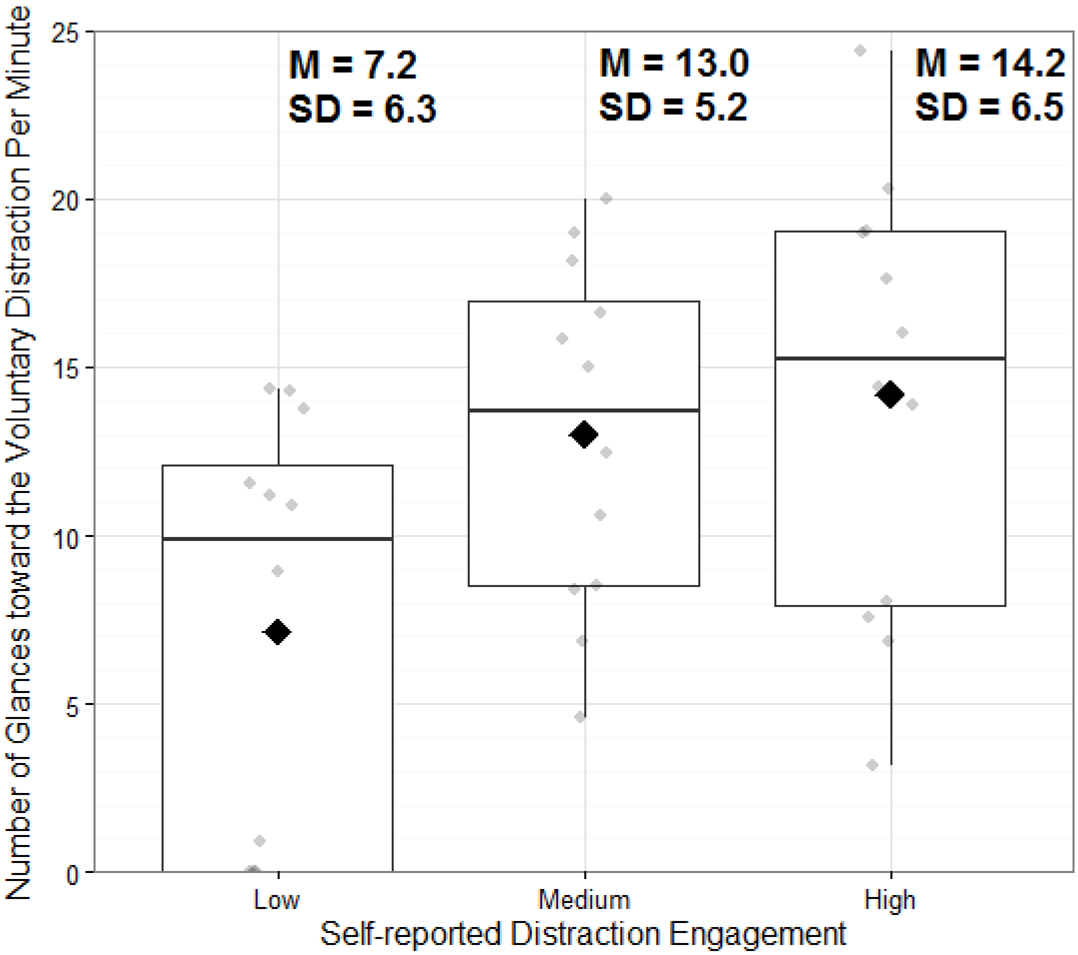


Figure 20: Boxplots of glances per minute toward the voluntary distraction during non-braking-event driving across SRDE levels

3.5.4.2 Driving performance and distraction type

For non-event-driving, the driving metrics of interest were average speed, speed variability, and SDLP. As mentioned previously, driving performance data from the three regions were not aggregated because region 1 was a rural road, while regions 2 and 3 were urban roads, and because region 2 occurred right after the left-turn gap acceptance task, so drivers may still have been accelerating in that region, while region 3 was not adjacent to any other driving event. Overall, the analysis used 302 data points for each dependent variable: 108 baseline, 108 involuntary, and 86 voluntary. Linear mixed models were built with distraction type, region, and their interaction as independent variables and participant as a random factor. Planned contrasts in post hoc analysis were used to compare driving metrics between categorical variable levels. All models, except the average speed model, used a logarithmic transform on the dependent variable to meet normality assumptions.

Average speed was significantly related to distraction type (Table 4). Average speed under voluntary distraction was 1.49 mph slower than baseline average speed (95% CI: -2.39, -0.60, *p* = .0004). There was no significant difference between involuntary and baseline average speeds (*p* = .35). Similarly, there was a marginally significant effect of distraction type on the average absolute deviation from the speed limit (*p* = .09). Under voluntary distraction, participants had 16% larger absolute deviations from the speed limit (95% CI: -1, 34, *p* = .05), but under involuntary distraction there was no effect (*p* = .46).

Although speed variability had a significant relationship with the interaction between distraction type and region (*p* = .02), planned contrasts did not show any conclusive evidence on how driving under distraction affects speed variability. In region 1, participants were observed having 34% greater speed variability under voluntary distraction compared to the baseline (95% CI: 4, 72, *p* = .02), in region 3, they were observed having 38% less speed variability (95% CI: 20, 52, *p* < .001), and in region 2, there was no effect (*p* = .55). Under involuntary distraction, in region 3, speed variability was marginally larger by 26% (95% CI: -1, 60, *p* = .06) than baseline driving, but no differences were observed in region 1 (*p* = .65), nor region 2 (*p* = .99) between these two conditions. Further, distraction type did not have a significant effect on SDLP (Table 4).

Table 4: Non-braking-event driving statistical modeling results. More detailed results showing removed interaction terms may be found in Appendix J

	Distraction type		Region		Region * Distraction type	
Response variable	F-value	p	F-value	p	F-value	p
Average speed	F(2,262) = 6.92	.001	F(2,262) = 1024.26	< .0001	--	--
Average absolute deviation from speed limit	F(2,262) = 2.41	.09	F(2,262) = 4.36	.01	--	--
Speed variability	F(2,258) = 4.41	.01	F(2,258) = 20.7	< .0001	F(4,258) = 3.01	.02
SDLP	F(2,262) = 2.28	.10	F(2,262) = 93.18	< .0001	--	--

Linear mixed models were built to examine the relationships between driving performance and SRDE under voluntary distraction (N = 324). Region, SRDE, and their interaction were independent variables, and participant was a random factor. Transforms were used on some of the dependent variables to meet normality assumptions: speed variability (square root transform), SDLP (logarithmic transform), and average absolute deviation from the speed limit (logarithmic transform). Under voluntary distraction, no significant relationships were found between SRDE and average speed, average absolute deviation from the speed limit, speed variability, nor SDLP (Table 5).

Table 5: Non-braking-event driving statistical modeling results using only samples from the voluntary distraction condition. More detailed results showing removed interaction terms may be found in Appendix J

	SRDE		Region	
Response variable	F-value	p	F-value	p
Average speed	F(2, 33) = 0.14	.87	F(2, 70) = 286.13	< .0001
Absolute deviation from speed limit	F(2, 33)= 0.61	.55	F(2, 70) = 5.05	.009
Speed variability	F(2, 33) = 0.54	.59	F(2, 70) = 38.10	< .0001
SDLP	F(2, 33) = 0.96	.39	F(2,. 70) = 19.79	< .0001

3.6 Discussion

The analysis from Experiment 1 found that self-reported distraction engagement was a good predictor of voluntary distraction engagement in simulated driving. Individuals with higher levels of self-reported distraction engagement frequency glanced at the in-vehicle display more often, and in total for a larger portion of time during a drive, than those with lower levels of self-reported distraction engagement frequency. Participants who had higher levels of self-reported distraction engagement also completed more tasks (marginally significant). Together, these findings provide evidence that the measures taken using the SDDQ voluntary distraction subscales are useful, such that individuals who self-assessed to be more prone to voluntary distraction indeed engage more often in voluntary distraction. There have been previous studies examining the reliability and validity of SDDQ self-reported measures of distraction engagement (Feng et al., 2014; Marulanda, Chen, & Donmez, 2015a) and the results of this thesis provide further evidence that it is appropriate to use them to predict self-reported distraction engagement.

It is interesting to note that participants from different SRDE groups did not show any difference in time to complete a task or in the total number of taps made in the overall drive. These two measures, total time and number of taps required to complete a task, may be indicators of secondary task performance (efficiency and correctness). Therefore, finding no differences in these measures provides evidence that the higher number of tasks completed associated with the high engagement group was due to willingness to engage, rather than their abilities to perform the secondary task.

Glances away from the road over 2000 ms can double the risk of a crash (Dingus et al., 2006) and are generally considered dangerous in the driving literature. For all but two participants, the average glance duration was under 2000ms, suggesting that participants were not generally taking excessively long glances when they were engaging with the secondary task provided.

Participants did engage with the involuntary distraction. On average, participants made 0.47 glances per stimulus, and overall 36% (143 of 396) of all stimuli presented were glanced at. An on-road distracted driving study focusing on advertising signs found active signs attracted 1.31 glances per subject per sign and billboards (passive signs) attracted 0.64 glances per subject per sign (exposure times and sign position were variable) (Beijer, Smiley, & Eizenman, 2004).

Strayer et al. (2003) observed 20 participants in a driving simulator experiment to glance at two thirds of the billboards presented to them while driving with and without a cellphone. In comparison to these studies on roadside advertisements, findings from this experiment indicate that the experimental stimuli used may be less distracting. This is expected because the experimental stimuli used in this study were designed to have minimal content in order to control the relevancy of the distraction. Further experimentation would be needed to identify if more distracting involuntary distractions (varying the capture power) would affect driving performance or individual differences in suceptibility to involuntary distraction.

Unlike the voluntary distraction section, the SDDQ section on involuntary distraction was not able to predict suceptibillity to involuntary distraction as assessed in this simulator experiment. The only significant relationship found was that drivers who indicated greater suceptibility had shorter average glance durations, which was the opposite of the questionnaire designers' expectations. Potential resons for the ineffectiveness of the involuntary subscales are that irrelevant stimuli may capture attention both automatically and unconciously (Theeuwes & Godijn, 2001; Irwin, Colcombe, Kramer, & Hahn, 2000), so people may not be able to directly report their suceptibility to involuntary distractions. In addition, daydreaming may not be an appropriate involuntary distraction item as it is an internal process and does not fit the definition of involuntary distraction because it is not related to supressing a response to external stimuli. A revised version of SDDQ (Marulanda et al., 2015b) was developed to address these issues, and is used in Experiment 2.

Lead vehicle braking produced interesting results and, as hypothesized by Regan et al. (2011), the psychological mechanisms involved for voluntary versus involuntary distraction appear to generate different patterns of interference. Under involuntary distraction, participants' ARTs in response to lead vehicle braking were delayed by 19%, leading to 12% shorter TTC_{min} values than the baseline. However, there were no differences in how quickly the participants glanced at the lead vehicle after its brake onset, suggesting that the delay in ART may not be due to a delay in perception but rather a cognitive delay or a lack of perceived urgency. Under voluntary distraction, participants also exhibited ART delays (23% slower than baseline), but since neither PTs nor ITs were significantly longer than the baseline, it is not clear if the delay is due to a delay in perception, inspection, or a combination of both of these. However, there was also a marginally significant decrease in their transition time from the accelerator to the brake pedal (i.e., “brake transition time” or BTT), a potential compensatory mechanism, which may have led to TTC_{min} values comparable to the baseline condition. In contrast to involuntary distraction, participants might have been more conscious of the potential negative effect of distraction, or perceived more urgency to respond to lead vehicle braking when they voluntarily engaged in the secondary task, even though, on average, gap times between the lead vehicle and the participants’ vehicle were larger under voluntary distraction than under involuntary distraction. Similar compensation behaviours in a braking response event has also been observed in D’Addario’s perception response study (2014) under an externally-paced (non-self-paced), continuously cued cognitive task and in a distraction mitigation study under an externally-paced discretely cued audio and visual tasks (Donmez, Boyle, & Lee, 2006).

Response delays, similar to the ones observed in Experiment 1 under voluntary distraction, have also been observed previously. Strayer et al. (2011) had participants follow a braking lead car in distraction conditions involving a continuously cued task (not self-paced): conversing on a hands-free and a hand-held cell phone. This study found that brake reaction times were slower and that participants took longer to recover their speed after braking events under both distraction conditions compared to the baseline condition. Delayed accelerator release times in response to lead vehicle braking events have also been observed in a self-paced voluntary distraction setting, using the same secondary task utilized in Experiment 1 (Donmez et al., 2007).

The left-turn gap acceptance task was not affected by the secondary task, possibly due to participants decoupling the gap acceptance task and the secondary task, or because of the design of the gap acceptance task. Gap acceptance has been used previously in distracted driving literature (Cooper & Zheng, 2002; Cooper et al., 2003; Regan, Young, Lee, & Gordon, 2008). In the Cooper et al. studies, participants drove through a closed course while performing a task that was not self-paced: listening to audible messages and responding to those messages. They were shown 100 gaps and told to indicate which ones they would take. Participants were observed being riskier in their decision making when distracted than when not distracted. The lack of significant results in the current study may be due to participants delaying their gap selection until after they have engaged in the secondary task, or delaying their secondary task engagement until they completed the gap acceptance task. In fact, the high and low SRDE groups were observed to having comparable glance and tap rates toward the voluntary distraction task during gap acceptance (from when they arrived at the intersections, until they completed their turns).

The glance rates of the low SRDE group during gap acceptance (M = 3.2 glance / min, SD = 4.7) and lead vehicle braking events were comparable (M = 3.5 glance / min, SD = 1.9), but were less than their overall glance rate (M = 9.0 glance / min, SD = 5.5). The glance rate of the high SRDE group during gap acceptance (M = 4.1 glance / min, SD = 5.0) was lower than both their lead vehicle braking event glance rate (M = 6.5 glance / min, SD = 3.1) and their overall glance rate (M = 15.3 glance / min, SD = 6.4). The direction of these differences indicate that the participants may have been modulating their interactions, reducing task interference. The lack of significant findings could also be because unlike the Cooper et al. studies, participants in the current study did not have to assess whether or not they would accept each and every gap, instead they only had to choose a single, optimal gap in which to turn.

Gap acceptance is a driving task that requires sensory and cognitive cues to help drivers make judgements about other vehicles' speed and distance. These cues may not be replicated in the 2-dimensional driving simulator environment and their absence may have affected gap acceptance task performance. In a driving simulator, the increasing size of the vertical vehicles is the main perceptual cue for drivers to judge distance, speed, and the vehicles' arrival time at an intersection (Alexander, Barham, & Black, 2002). Simulator experiments have been used previously to study gap acceptance tasks despite these limitations (e.g., Alexander et al., 2002; Yan, Radwan, & Guo, 2007). Non-simulator studies observing gap acceptance across traffic have found that drivers' median accepted gap time ranges from 4.5 to 7.5 s with an estimated additional second for gaps accepted when performing left-turn maneuvers across traffic (see Alexander et al., 2002 for review). In this experiment, the median gap accepted was 6 seconds for baseline driving, indicating it is likely that the simulated gap acceptance task, although not an exact replication of a real-world gap acceptance task, is a valid approximation.

For non-braking-event driving, performance changed only with voluntary distraction: average speed for non-braking-event driving was 1.49 mph slower than baseline average speed and 1.02 mph slower than involuntary distraction average speed. Similarly, there was a significant increase in deviation from the speed limit under voluntary distraction. In previous research, speed maintenance decrements under distraction have been related to the amount of attentional capacity required by the secondary task (Lee et al., 2008). The distractions tested did not produce a significant effect on SDLP, nor did they have a consistent effect on speed variability, possibly because these metrics were more affected by the driving environment than the distraction conditions (Bella, 2013; Charlton et al., 2010).

Self-reported distraction engagement was a significant predictor of most distraction engagement metrics under the voluntary distraction task, but it was only a significant explanatory variable for maximum deceleration in response to lead vehicle braking events. Maximum deceleration was found to be significantly affected by the interaction between SRDE and gap time at the start of the lead vehicle braking event. When high SRDE drivers had shorter gap times, they braked harder. This effect may be due the high SRDE drivers responding with more urgency at smaller gap times as they were engaging more with the distraction during the braking event (both prior to and while the lead vehicle braked).

It appears that involuntary and voluntary distraction affect driving performance differently, but due to limitations with SDDQ involuntary subscale, drivers’ involuntary distraction engagement could not be related to any self-reported measures. Experiment 1 was also limited with respect to the complex design of the simulated drive, since two of the hazard events previously mentioned suffered from confounding effects and could not be used. In addition, involuntary distraction engagement metrics could not be compared to participants’ individual cognitive abilities because the modifications made to the flanker task created for Experiment 1 made it invalid. Thus, Experiment 2 delved more deeply into understanding the effects of involuntary distraction, using shorter drives with fewer events, unmodified cognitive tasks, and a pilot participant group to help fine-tune driving scenario and involuntary distraction stimuli designs.

Chapter 4

4.0 Experiment 2

4.1 Summary

Experiment 2 further investigated involuntary driver distraction in simulated driving, including the modulating effects of environmental visual complexity (i.e., urban and rural environments). Perception research posits that in tasks with low perceptual load, spare perceptual capacity not used by task-relevant stimuli involuntarily “spills over” and is used to perceive task-irrelevant distractors. However, when a task requires high perceptual load, distractor processing is prevented because perceptual load capacity is exhausted. Thus, drivers may be better at inhibiting irrelevant stimuli (i.e., involuntary distraction) when driving under high perceptual load. In addition, self-reported and cognitive measures were tested against measures of susceptibility to involuntary driver distraction in simulated driving to better understand involuntary driver distraction facilitators.

To test the hypotheses that individual differences and variance in environmental perceptual load may affect distraction inhibition, an additional 24 participants were observed in the simulator under two distraction conditions (involuntary distraction: unexpected irrelevant stimuli appeared on a secondary display during driving, and baseline: no distraction) and two visual perceptual loads (an urban road imposing higher perceptual load and a rural road imposing lower perceptual load). Further, the flanker (Eriksen & Eriksen, 1974) and Stroop (Stroop, 1935) tasks were administered to measure inhibition ability to resist distractor (irrelevant stimuli) interference (flanker) and ability to inhibit automatic responses (Stroop). In addition, each participant filled out self-reported attention measures: everyday distractibility section of Cognitive Failures Questionnaire (CFQ) (Broadbent et al., 1982) and the involuntary distraction engagement section of the revised SDDQ (Marulanda et al., 2015b). In each experimental condition, the driver was tasked with maintaining the speed limit while following a lead vehicle, which braked multiple times throughout the drive. Similar to the findings of Experiment 1, participants in Experiment 2 also had delayed accelerator release times under involuntary distraction. Further, accelerator release times were also delayed more in the rural environment compared to the urban one.

The delay in ART is possibly due to a cognitive delay or a lack of perceived urgency to brake since there were no significant differences between distraction and baseline conditions in how long it took the participants to notice the braking lead vehicle. Contrary to the hypothesis, perceptual load had no effect on glances to the irrelevant stimuli and there was no significant relation between these glances and cognitive task measures. However, self-reported everyday distractibility, as measured by CFQ, correlated with length of glances towards the irrelevant stimuli. In addition, participants who glanced multiple times at the involuntary distraction had a marginally greater average revised SDDQ involuntary subsection score: meaning these participants self-reported both more difficulty ignoring distraction and a greater frequency of looking away from the road for longer than intended than participants who glanced only once or not at all.

4.2 Perceptual loading in Experiment 2

In order to examine if involuntary driver distraction effects change under varying perceptual load, perceptual load was adjusted using traffic density and visual clutter similar to Horberry et al. (2006). These driving environment attributes were chosen because, as mentioned previously, Forster and Lavie (2008) suggest that added perceptual load due to greater traffic density may make drivers less susceptible to distraction from billboards, and because results from a study by Horberry et al. (2006) suggest that increasing clutter (which increases the number of stimuli that may be relevant to the driving task, and thus should increase perceptual load) does not increase cognitive load.

The low perceptual load condition used a rural environment with a uniform straight road, some grass and distant trees on the side of the road and sparse traffic. A high perceptual load was imposed using more than double the amount of oncoming traffic experienced during the low perceptual load drive. Visual clutter was also increased in the high perceptual load by using an urban environment with buildings, controlled intersections (with traffic lights set to green so participants would only brake in response to driving events), and a four lane road instead of a two lane road. Some curvature was used in the urban environment for technical reasons related to the simulator, but because curves may increase both cognitive and perceptual load, and as stated by Load Theory, high cognitive load may increase distractor interference by hindering the cognitive control functions that help maintain stimuli processing priorities, experimental data of interest were only collected on straight road sections.

4.3 Method

4.3.1 Participants

Participants were recruited using online, email, and poster advertisements in Toronto, Canada (Appendix K), and were selected based on their responses to a screening survey (Appendix L). The participants had to be native English speakers, have normal or corrected to normal vision, be able to wear contact lenses during the simulator experiment, have had their full driver's license for at least 3 years, and be between the ages of 21 and 35. Younger drivers who have less driving experience were excluded because lack of driving experience reduces spare attentional capacity (Young et al., 2007). Older drivers were also excluded as they can have decreased visual and cognitive capacity as well as delayed reaction times (Ho, Scialfa, Caird, & Graw, 2001). The participants were asked about their physical and health status to identify and exclude participants who may be prone to simulator sickness.

Twenty-five participants were recruited for the simulator study. One participant's data were removed from the analysis due to poor eye tracking quality, most likely caused by heavy eye makeup. The 24 participants whose data were analyzed, self-reported to having 3 to 17 years of full licensure (M = 6.4 years, SD = 3.5 years) and being between the ages of 21 and 34 (M = 26 years, SD = 3.4 years). A total of 19 participants had never used a driving simulator before and the remaining 5 had used a driving simulator once or twice previously in their lives.

4.3.2 Apparatus

The apparatus used was the same simulator and eye tracking setup described in Experiment 1. The eye tracker cameras were positioned on the right side of the dashboard display (rather than centred, as they were in Experiment 1) to be closer to the secondary display to improve the accuracy of eye tracking metrics toward the secondary display.

4.3.3 Experimental design

As mentioned above, perceptual load was manipulated by the use of urban and rural environments and thus driving environment was an independent variable. Distraction type was the other independent variable and also had two levels: distraction (involuntary) and no distraction (baseline). Both independent variables were within subject and they were crossed; each participant drove through four experimental drives. The order of experimental drives was counterbalanced across participants to control for order effects (Appendix M).

4.3.4 Distraction stimuli

This study used custom distractions (Figure 21) similar to the ones used in Experiment 1. Past research has shown that salient stimuli capture attention automatically even when these stimuli are irrelevant. Stimuli with abrupt onsets are more likely to cause this automatic capture effect (Yantis & Jonides, 1990). Hence, the involuntary distraction used in this study consisted of a chime sound followed by an abrupt onset of a 7 second geometric animation. The animations were chosen based on a pilot study of 8 participants who were asked to order 10 different animations presented on the secondary display with respect to how distracting they thought the animations were while they looked at the road ahead. The four animations rated to be the most distracting were chosen. Each animation was shown only once during each distraction drive and at a fixed time and position. Drivers were told that they did not need to interact with the display when it played the animation and sound. However, drivers were not aware when the stimuli would occur in the distraction drives. Prior to the distraction drives, participants were told: *"For this drive there will be a sound and an animation that appear on the display periodically. You do not need to interact with it."*

The simulation initiated the distraction 1.5 seconds prior to the onset of the braking event. Due to simulation software delays, the distraction was shown after this initiation time (M = 1.67 seconds, SD = 1.26 seconds) right around when the lead vehicle braking lights were onset.

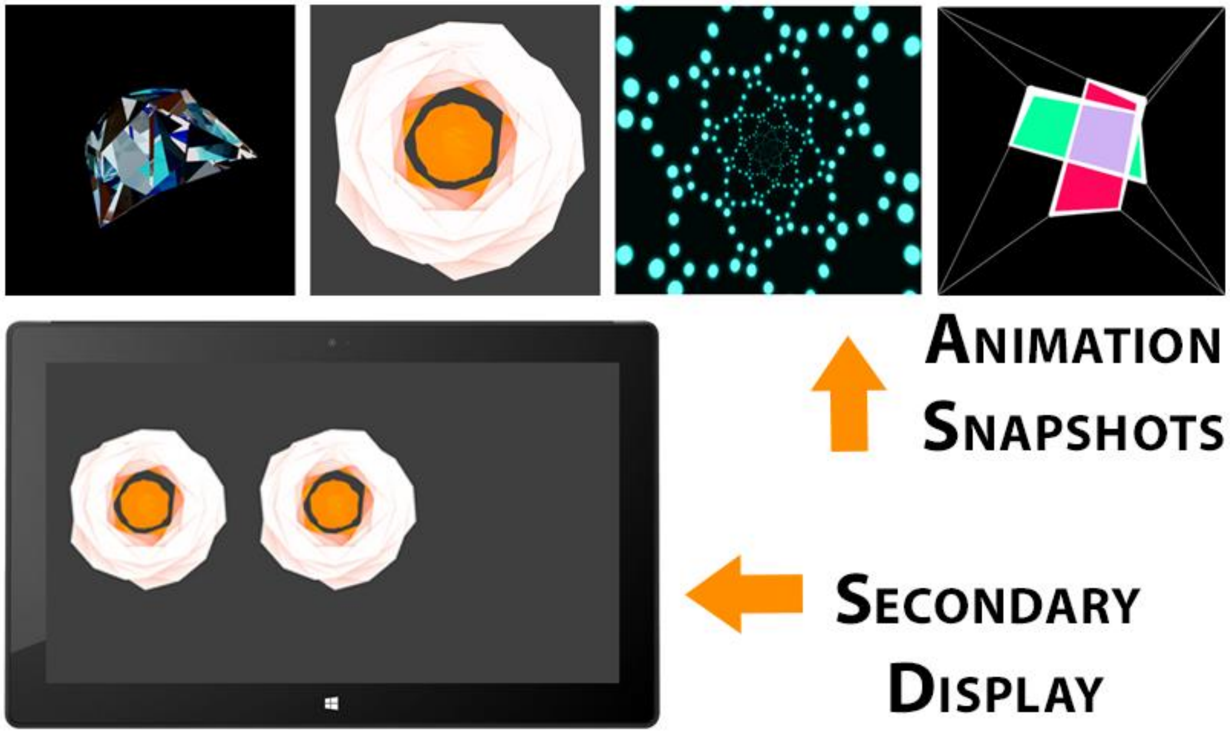


Figure 21: The involuntary distraction used in Experiment 2 as it appears on the secondary display. Each graphic was 600x600 pixels and was displayed once per drive on the 208 dpi screen. These animations were sourced from: http://www.89a.co.uk/post/34407365222/doughnut, https://milnersblog.files.wordpress.com/2012/06/digital-geometric-gif-animations-diamonds-milnersblog.gif?w=474, http://giphy.com/gifs/art-meets-dizzying-H7PXggaswcgBG, and http://patakk.tumblr.com/post/20424077892

4.3.5 Driving scenarios

The urban environment included many buildings, intersections, stationary pedestrians, and oncoming traffic. Whereas the rural environment only had 8 oncoming cars per drive, the urban environment used 18 oncoming cars per drive to increase traffic density. Participants were told to maintain 35 mph in the urban environment and 50 mph in the rural environment. For both conditions, the simulated road (both lanes) was 12 feet, or 3.66m, across. Curvature was introduced in the urban road (Figure 22) to block the view of the driver from the entire city road. This visual obstruction served two purposes: to create a more realistic scenario and to prevent overloading the driving simulator's graphics engine by reducing the number of elements that the simulator needed to render at a given time. On average, the drive in the urban condition took 3 minutes 49 seconds (SD = 5.5 seconds) and the drive in the rural condition took 4 minutes 42 seconds (SD = 5.7 seconds).

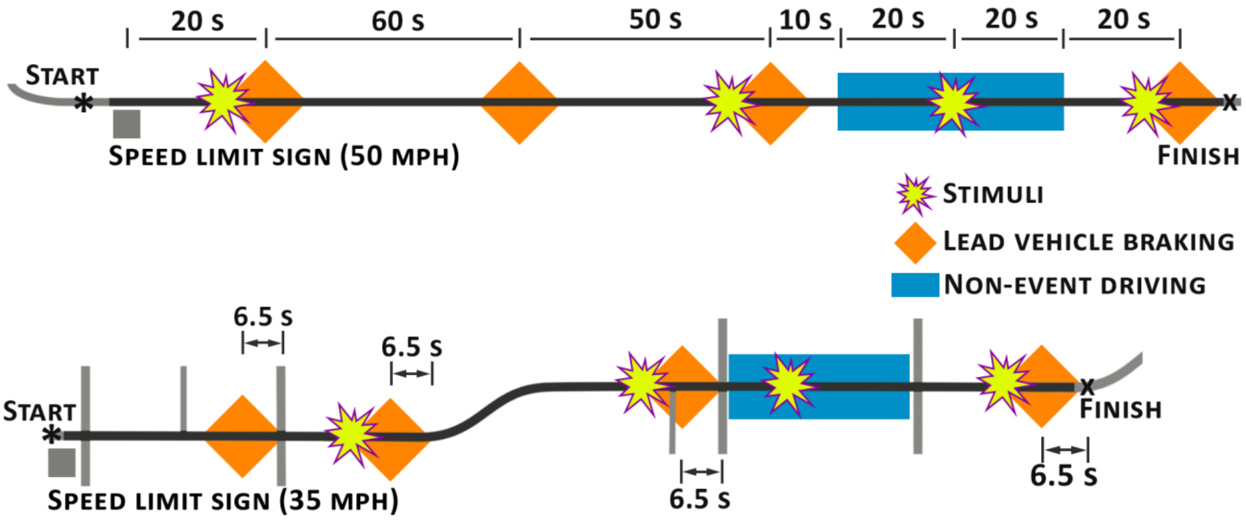


Figure 22: Event locations in the rural drive (A) and the urban drive (B) for Experiment 2. Events were designed not to occur in traffic light controlled intersections

In all drives, the participants were asked to follow a lead vehicle. Prior to each drive, participants were told the following: "*Driving is your primary task. This is not an experiment in risk taking; your main task, as in the real world, is the safe operation of the vehicle. Please drive as you normally would in your actual vehicle. Please follow the car in front of you and do not pass. The car in front of you may adjust its behaviour to yours or may also brake periodically. Unless the car in front of you is braking, try to maintain the speed limit.*"

Lead vehicle braking events (Figure 23) were used to capture the effects of distraction on perception and reaction time. There were four lead vehicle braking events within each drive. In the distraction conditions, three of these braking events happened in conjunction with the onset of distracting stimuli. In the baseline conditions, no stimuli were present. For 20 seconds prior to lead vehicle braking onset, the lead vehicle's speed was smoothly adjusted to obtain time headways of 2.1 s. Maximum (70 mph) and minimum (40 mph) lead vehicle speeds were introduced to avoid excessive speeding or slowing down during the headway adjustment. Headway control ceased when the lead vehicle braked at a rate of 0.5 g (gravitational acceleration) for 7 seconds. This particular headway time and this deceleration rate were chosen because this combination created a scenario where participants in the pilot study felt urgency to brake, but did not feel as though the scenario was an emergency situation.

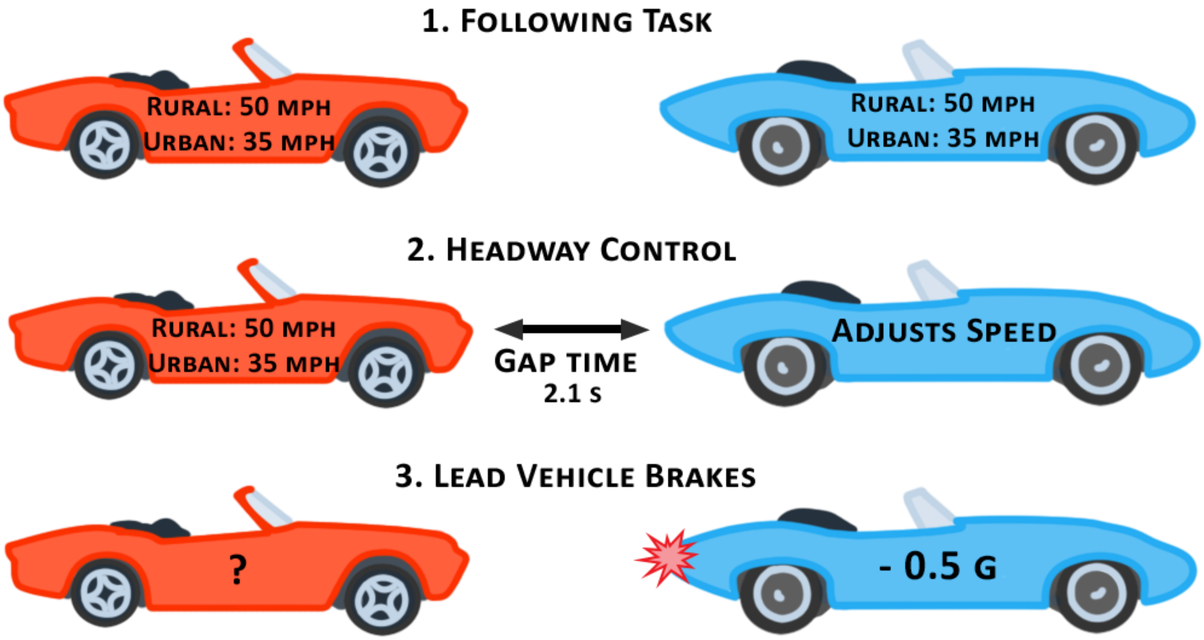


Figure 23: Experiment 2 lead vehicle braking event design

4.3.6 Procedure

The driving simulator experiment was part of a larger experiment, which took approximately 2.5 hours per participant, with the driving portion lasting approximately 1 hour. First, participants reviewed and signed the informed consent form (Appendix N). They then completed the revised SDDQ, performed a colour blindness test to verify their eligibility for the cognitive tasks, completed the flanker task, the Stroop task, and a number-letter task (Rogers & Monsell, 1995). They then performed the driving portion of the experiment. After the driving portion, participants performed an n-back task (Kirchner, 1958) and the Wisconsin card sorting test (Berg, 1948). The number-letter task, the n-back task, and the Wisconsin sorting test were used to help validate the revised SDDQ as part of a second project and are beyond the scope of this thesis. The flanker and Stroop tasks are described in more detail in Section 4.4.3.

During the driving portion of the experiment, the experimenter guided the participants through eye tracker calibration, providing further warnings to participants about simulator sickness, and giving them an overview of the experiment (see Appendix O for detailed experimenter guidelines). Participants first drove through a rural roadway with no other vehicles, to acclimatize them to the dynamics of the simulator. For this drive, participants were told to maintain 35mph, then maintain 50mph, brake lightly, brake as they normally would in their vehicle, and brake as they would in an emergency. Each participant then performed two practice drives. One practice drive used the rural road-way and one drive used the urban road-way utilized in the experimental drives, including the lead vehicle following task and the braking events, but with no distraction. The order of practice drives was counterbalanced across participants. If, in the practice drives, participants were driving very slowly (less than 5mph below the speed limit) or falling far behind the lead vehicle they were supposed to be following, they were instructed to *"Follow the lead car at a close but safe distance, as if following it to a destination".*

Participants were encouraged to take breaks before the experimental drives. Participants then drove the four experimental drives: rural baseline, rural distraction, urban baseline, and urban distraction (in a counterbalanced order). Participants were also encouraged to take breaks between every two drives. After each drive, participants were asked how alert they felt in order to monitor their fatigue. If a participant reported not feeling alert, the participant was encouraged to take extra breaks to walk around and drink water in order to reduce fatigue. At the end of the driving experiment, participants were asked to rate how distracting they found the involuntary distraction in each of the two environments (not distracting, a little distracting, distracting, or very distracting) (Appendix P). All participants were compensated $40 for their participation.

4.4 Measures

4.4.1 Simulated driving metrics

4.4.1.1 Distraction engagement

Distraction engagement metrics of interest were the average duration, the total duration, and the number of glances to the distraction, and the glance initiation time described previously in section 3.3.2 (Table 1). Eye tracking with the faceLAB system was used to assess participants' visual engagement with the involuntary distraction. Glance data from faceLAB were verified through manual video coding performed by one individual using video recorded from the

Surface Pro 2’s camera. Only glances over 100ms were used in the analysis, and glances were defined as described in section 3.3.2.

4.4.1.2 Lead vehicle braking

Lead vehicle measures used are the same as those described in section 3.3.3, Figure 7, and Table 2.

Overall, data from 288 total braking events were of interest. From the distraction condition, the events that were preceded by the animation were selected. From the no distraction (baseline) condition, the events from the corresponding locations were selected. Of these, 5 events were removed because the throttle was released prior to the event, 1 was removed because the participant did not brake in response to the lead vehicle braking, 1 was removed because of missing data for gap time, and 1 was removed because of missing time to collision data. Further, 15 events were removed due to the gap times at the beginning of the event being 2 standard deviations away from the mean gap time (M = 2.8 s, SD = 1.5 s). As mentioned previously, the participants were told to maintain the target speed (50 mph on rural roads, 35 mph on urban roads), unless the vehicle in front of them was braking. This instruction was used to better control for gap time between the participant’s vehicle and the lead vehicle prior to a braking event. Prior to the braking event (while the lead vehicle was adjusting headway time), none of the participants who released the throttle after the event started and braked in response to the event, drove on average 15mph less than the speed they were told to maintain. Thus no data were removed because participants drove too slowly prior to the braking events.

After these events were removed, there were 265 braking events eligible for analysis (rural baseline: 67, urban baseline: 66, rural distraction: 64, urban distraction: 68). These events were then aggregated to the level of distraction type X driving environment, resulting in N = 96 data points each for ART, BRT, BTT, maximum deceleration, and minimum time to collision. Further data were lost for perception time: in 113 out of these 265 eligible events, the participant’s gaze was already on the lead vehicle when the event started. In an additional event, the gaze data quality was poor. Therefore, there were 151 braking events eligible for the analysis of perception time (rural baseline: 41, urban baseline: 37, rural distraction: 38, urban distraction: 35). These events were then aggregated to the level of distraction type X driving environment, resulting in N = 84 data points for perception time analysis.

Out of the 265 eligible events reported above, 17 were lost for inspection time analysis because the accelerator was released before inspection time period started. Therefore, there were 248 braking events eligible for the analysis of inspection time (rural baseline: 58, urban baseline: 62, rural distraction: 62, urban distraction: 66). These events were then aggregated to the level of distraction type X driving environment, resulting in N = 95 data points for inspection time analysis.

There was one collision in the distraction condition, during the last braking event for one participant. The braking metrics for that event were removed from the analysis in the earlier data cleaning steps (in this case because the throttle was not engaged at the start of the braking event).

4.4.1.3 Non-braking-event driving

A stretch of road where the involuntary distraction was displayed, but where no lead vehicle events occurred, was used to examine SDLP, average speed, and speed variability changes under distraction. The roadway of interest was from when the stimulus was onset to when the driver reached the next intersection in the urban drive (1531 ft, or 30 seconds when driving 35 mph) and for 20 seconds after the third brake in the rural drive (1467 ft when driving 50 mph) (Figure 22). The same portions of roadway were also used from the baseline conditions. Since this experiment required participants to perform a speed maintenance task, the average absolute deviation from the target speed was also analyzed.

4.4.2 Post-driving simulator survey

As mentioned earlier, at the end of the driving simulator experiment, participants were asked to self-assess how distracting they found the involuntary stimuli:

- How distracting did you find the sound and animation that played on the display in the urban environment?
- How distracting did you find the sound and animation that played on the display in the rural environment?

They could respond to each environment-specific distraction assessment question with: Not distracting (1), a little distracting (2), distracting (3), or very distracting (4). These questions are referred to in the analysis as the urban or rural distractor ratings.

4.4.3 Metrics from the laboratory cognitive study

Cognitive task measurements and self-reported measures were used to determine relationships between individual differences, driving performance, and distraction engagement in the simulator. Flanker and Stroop tasks both measured inhibitory control and the results from these tasks were related back to the driving simulator experiment.

4.4.3.1 Self-reported measures

The following self-reported measures are predictor variables used to estimate participants' distraction engagement in simulated driving.

Self-reported driving history was collected in the screening survey: how often participants drove (participants could choose one of five responses from never to almost every day) and how many kilometers participants had driven in the last year (four options from under 10,000 km to over 50,000 km). Several other self-reported measures were also collected during the cognitive assessment including how much technological experience participants had and how readily they adopt new technology.

During the experiment, participants were asked to respond to the 8 everyday distractibility items from the Cognitive Failures Questionnaire (CFQ) (Appendix Q), and the involuntary distraction themed questions from the revised SDDQ (Appendix R). The everyday distractibility CFQ items (Broadbent et al., 1982) were used to investigate the association between involuntary distraction and cognitive failures (the likelihood of a person performing an error in everyday tasks) resulting from inattention. CFQ has previously been used to assess how cognitive failures may relate to traffic crashes, although higher overall CFQ scores were related to increased driver error rates, not increased crashes (Allahyari et al., 2008). Each item on CFQ is measured on a frequency scale from 0 to 4 anchored at 'never', 'rarely', 'sometimes', 'often', and 'very often.' Thus, for scoring purposes, a sum score was calculated by adding responses across all items and participants could have a CFQ score ranging from 0 to 32. Higher values correspond to greater distractibility.

Two sections of the revised SDDQ were relevant to involuntary distraction. The individual questions for these items are reported in Appendix R. The scale for Involuntary 1 (difficulty ignoring distractions) was measured from 1 to 5, anchored at 'not at all', 'small extent', 'moderate extent', 'large extent', and 'extremely large extent'. The scale for Involuntary 2 (looking away for longer than intended) was measured from 1 to 5, anchored at ‘never’, ‘rarely’, ‘occasionally/sometimes’, ‘often’, and ‘very often’. The score of each section was the mean of all items within the section. Higher values correspond to greater distractibility.

4.4.3.2 Flanker task

The flanker task (Eriksen & Eriksen, 1974) is used to assess inhibitory control by examining participants’ ability to suppress responses to irrelevant information. The flanker measures resistance to distractor (irrelevant stimuli) interference by measuring response times to a centrally presented stimulus that is flanked by distractors that may activate the same response channel as the target. Studies have found that response times are higher when the flanker stimuli are incongruent (as opposed to congruent), indicating that the distractors are processed even though they are irrelevant to the task. This effect is known as the *flanker compatibility effect*. The modified version based on Roper, Cosman, and Vecera (2013) used in Experiment 2 is designed with two perceptual load conditions that have been shown to alter flanker interference effects: non-target stimuli that generate efficient searches (low perceptual load) produce increased flanker interference effects, while the non-target stimuli that produce less efficient searches (high perceptual load) reduce flanker interference effects.

The low perceptual load condition used circles with a gap to one of four sides as non-targets (Figure 24). The high perceptual load condition used the letter “L” with equal-length line segments displayed at 0°, 90°, 180°, or 270° as non-targets (Figure 25). Both the target and non-targets subtended a visual angle of 3°x3°. The target was a ‘sideways T’ pointing to the left or to the right, which randomly appeared at one of the 6 fixed locations among the non-targets. The distractor, also a ‘sideways T’, presented to the right or left of these 6 fixed locations, could be congruent (i.e., point in the same direction as the target) or incongruent (i.e., point in the opposite direction as the target).

Each stimulus was displayed for 100 ms. Participants were asked to indicate the direction of the target by pressing the left shift key on the keyboard if the target was facing left, or the right shift key if the target was facing right. The next trial started 1 s after a response was made. Participants were instructed to respond both as accurately and as quickly as they could. Accuracy and response time were recorded.

Figure 24: Example displays of the <u>low</u> perceptual load task in the flanker task: Low target/non-target similarity with incongruent flanker (Left) and congruent flanker (Right)

Figure 25: Example displays of the <u>high</u> perceptual load task in the flanker task: High target/non-target similarity with incongruent (Right) and congruent (Left)

When performing the flanker task, participants were seated approximately 55 cm from the task monitor (Figure 26). The stimuli were presented on a uniformly white screen and the room was dimly lit. The stimuli would then appear, containing one target, one distractor (flanker), and five non-targets. The flanker subtended a visual angle of 3.48°x3.48° to compensate for the reduced acuity resulting from its off-centre position as it was located 3.14° to the right or the left of the centre of the screen.

Figure 26: Experimental setup for cognitive tasks. The head/chin rest was used for the flanker task

Prior to the start of each perceptual load condition, participants completed a practice session consisting of 6 trials. The flanker task session was divided into 2 blocks of trials (low vs. high perceptual load condition), each consisting of 96 unique stimuli (2 target directions x 2 congruencies x 6 target locations x 2 positions of the flanker on the screen). For each stimulus, the orientation of the non-targets was randomized, but the same non-target orientation never appeared more than twice. The flanker task was counterbalanced by ensuring that half of the participants completed the low perceptual load block first and the other half completed the high perceptual load block first.

Mean reaction times were computed using only the correct responses for each participant. Reaction times outside ±2.5 SD from each participant-by-condition mean were excluded from the analysis following Roper et al. (2013): 2.19% of the data were trimmed in the low perceptual load condition and 2.72% of the data were trimmed in the high perceptual load condition.

For the flanker task, performance was measured using the relative change in mean reaction time between the congruent ($\boldsymbol{Congruent_{RT}}$) and incongruent ($\boldsymbol{Incongruent_{RT}}$) trials in the low perceptual load condition and is calculated using the equation below. This calculated metric ($\Delta\boldsymbol{RT_{flanker}}$) is referred to as the relative flanker compatibility effect in this thesis (R_{FCE}).

$$\Delta \boldsymbol{RT}_{\boldsymbol{flanker}} = \left(\frac{\boldsymbol{Congruent}_{\boldsymbol{RT}} - \boldsymbol{Incongruent}_{\boldsymbol{RT}}}{\boldsymbol{Congruent}_{\boldsymbol{RT}}}\right) \times \mathbf{100}$$

The low perceptual load trials were used for examining individual differences in distraction susceptibility because the flanker task is designed to induce high distraction effects in the low perceptual load condition and low distraction effects in the high perceptual load condition (Roper et al., 2013). Thus, individual differences in distraction inhibition should be more salient in the low perceptual load condition. Zero values were assigned to participants who did not exhibit a flanker effect (their flanker compatibility was negative, i.e., their reaction times were faster in the incongruent trails than in the congruent trials).

As for investigating the distraction effects within urban and rural environments, the following metric was generated, which captured the change in flanker performance between the high and low perceptual load conditions. Flanker compatibility in the below equation refers to the difference between the congruent and incongruent reaction times for the perceptual load trial specified in the subscript. This metric ($\Delta \boldsymbol{Flanker\ Compatibility}_{\boldsymbol{hard\ vs\ easy}}$) is referred to as the relative change between high and low perceptual load flanker compatibility effects ($\mathrm{RHL}_{\mathrm{FCE}}$) in this thesis.

$$\Delta \boldsymbol{Flanker\ Compatibility}_{\boldsymbol{high\ vs\ low}} = \left(\frac{\boldsymbol{Flanker\ Compatibility}_{\boldsymbol{low}} - \boldsymbol{Flanker\ Compatibility}_{\boldsymbol{high}}}{\boldsymbol{Flanker\ Compatbility}_{\ \boldsymbol{low}}}\right) \times \mathbf{100}$$

Flanker task performance is usually analyzed by examining the differences in average response times between congruent and incongruent trials (flanker compatibility), and the change in flanker performance between perceptual load levels is usually measured by calculating the difference between flanker compatibilities in the high and low perceptual load conditions (Roper et al., 2013). In order to rank participants' abilities to suppress responses to irrelevant information, the standardized versions of these measures, $\mathrm{R}_{\mathrm{FCE}}$ and $\mathrm{RHL}_{\mathrm{FCE}}$, are used instead in this experiment.

4.4.3.3 Stroop task

The Stroop task, developed by Stroop (1935), is designed to capture inhibition of automatic behaviour by measuring the time it takes for participants to correctly name the colour of the ink in which an incongruent word is presented (e.g., the word BLUE in red ink). The automatic reading behaviour interferes with the naming of the ink colour, resulting in a slowed response.

In the task trials, participants must correctly identify the colour of the text stimuli displayed to them. Participants complete 120 trials consisting of 3 different types of stimuli: (1) neutral type: 48 trials in which the stimuli is a string of asterisks (i.e., ****) printed in different colour fonts (red, blue, green, and yellow); (2) incongruent type: 48 incongruent trials in which a colour name is printed in a font of a different colour (e.g., ‘red’ printed in yellow font); and (3) congruent type: 24 congruent trials in which a colour name is printed in the same font colour (e.g., ‘red’ printed in red font). Participants respond using the ‘1’, the ‘2’, the ‘3’, and the ‘4’ keys on the keyboard. Each key corresponded to a font colour (1 = red, 2 = blue, 3 = green, 4 = yellow).

Before the experimental trial, participants practiced the mapping of the keys to the colours. This practice block consisted of 16 trials (4 trials for each colour) of neutral stimuli presented in a random order where no colour was presented twice in a row. Participants were required to achieve an average accuracy greater than 85% to ensure that they had memorized the mapping of the keys to the colours. If they had insufficient accuracy, participants repeated the block a second time. Participants would have been disqualified from the Stroop task if they had not achieved the required accuracy, but none of the driving simulator participants were disqualified. Following the initial practice block, participants were provided with a second practice block of 15 trials that contained all three stimuli types (5 congruent, 5 incongruent, and 5 neutral).

Only correct trials longer than 200ms were analyzed. For the Stroop task, performance was measured by the relative change in average response time between neutral trials and incongruent trials (calculated using the equation below). This metric ($\Delta \boldsymbol{RT_{stroop}}$) is referred to as relative interference (RI) in this thesis. A larger response time difference between the Stroop tasks’ neutral and incongruent trials indicates lower distractor inhibition.

$$\Delta \boldsymbol{RT_{stroop}} = \left(\frac{\boldsymbol{Neutral_{RT} - Incongruent_{RT}}}{\boldsymbol{Neutral_{RT}}}\right) \times \mathbf{100}$$

Although Stroop task performance is usually measured by examining the difference in average response times between the neutral and incongruent trials, the standardized measure $\Delta \boldsymbol{RT_{stroop}}$ was used in this experiment in order to rank participants’ inhibition abilities.

4.5 Hypotheses

For this experiment, it was expected that greater distractibility captured through the self-report measures, the cognitive tasks, and the distraction engagement in the simulator would be related and positively correlated. In addition, driving performance effects observed in Experiment 1 were expected to be replicated. Thus, under involuntary distraction, participants were expected to experience a delayed ART, with no significant difference in BTT for an overall delayed BRT. It was not expected that there would be any performance differences in the non-braking-event portions due to the short duration of the distraction (similar to what was observed in Experiment 1). However, if there was an effect, it would most likely be that drivers would drive slower in the presence of the stimulus than in baseline driving as drivers have previously been observed driving at lower speeds in the presence of video advertisements (Chattington et al., 2009).

4.5.1 Distraction engagement metrics across driving environments

Participants who are less able to inhibit distraction should have more glances toward the distraction stimuli, longer glance durations, and shorter glance initiation times after stimulus onset. It was expected that these measures would correlate with the cognitive task and self-report measures. Due to high visual load, it was hypothesized that these distractibility tendencies would be less evident in the urban driving environment than in the rural environment.

4.5.2 Distraction engagement metrics across demographics

As assessed by driving history and technology exposure questions, drivers with more experience were expected to be more comfortable handling the cognitive load of the driving task and to glance more at the distraction because of their larger spare capacity. Similarly, drivers reporting more experience with technology could be less overwhelmed with both the simulator and the secondary display and could have more spare capacity to glance more at the distraction stimuli.

4.5.3 Distraction engagement metrics versus measures of susceptibility to distraction

It was expected that larger ratings on the involuntary section of the revised SDDQ, higher CFQ scores (which indicate higher self-reported cognitive failures), and worse performance on the Stroop and the flanker tasks would be positively correlated with increased participant glance frequency and glance durations towards the involuntary stimuli as well as shorter glance initiation times.

Since the change in the flanker task results between high and low perceptual load conditions indicate how individuals inhibit distraction under high versus low perceptual loads (Roper et al., 2013), it is possible that RHL_{FCE} may be related to differences in how much participants engaged with the distraction between the urban (high load) and rural (low load) driving environments.

4.6 Results

4.6.1 Distraction engagement measured through glance behaviours

Of the 24 participants analyzed, 8 did not look at any stimuli during the experiment and thus the glance dataset analysed included only data from the 16 participants who made at least one glance towards the stimuli. Out of the 16 participants: 10 looked at both the first stimulus shown and some subsequent stimuli and 6 only looked at the later stimuli. Out of these 6, four participants made only one glance toward a later stimulus. Overall, only one participant had (two) glances longer than 2 seconds. In this experiment, there were 0.54 glances per subject per stimulus, and overall participants glanced toward 40% of all stimuli presented (77 of 192).

The average number of glances per participant was 6.5 (SD = 4.5), with an average glance duration of 684 ms (SD = 204 ms) and an average glance initiation time of 2474 ms (SD = 2294 ms). The average number of glances to a given stimulus (there were eight total over the two distraction drives) was 1.35 (SD = 0.64), with an average glance duration of 735 ms (SD = 398 ms) and an average glance initiation time of 2055 ms (SD = 1478 ms). These glance behaviours are similar to those observed in Experiment 1 under involuntary distraction, where, overall, participants glanced an average 5.22 times (SD = 5.46). The average number of glances to a given stimulus (there were eleven total over the two distraction drives) was 0.86 (SD = 0.17) with an average glance duration of 548 ms (SD = 207 ms), and average glance initiation times of 1329 ms (SD = 929 ms).

To understand if the first stimulus was more distracting, potentially due to novelty or unexpectedness (Parmentier, 2008), the glances from the 10 participants who glanced at the first stimulus were analysed to see if there was a significant difference between their engagement with the first versus the later stimuli. Two linear regression models were built: one with glance duration and the other with glance initiation time as response variables. The independent variable used was a binary factor indicating whether the metric was observed during the first stimulus or averaged from subsequent stimuli. There was no significant effects found either for glance duration ($F(1, 9) = 0.46$, $p = .52$), or for glance initiation time ($F(1, 9) = 0.03$, $p = .87$).

4.6.1.1 Effects of environmental conditions

Contrary to expectation, no significant differences were found in glance metrics toward the irrelevant stimuli between the rural and the urban environments (Appendix S). Participants' post-drive rating of how distracting they found the involuntary distraction was also not different between the two environments (Appendix S).

4.6.1.2 Effects of driving experience, technology exposure, and self-reported attentional measures

For the purpose of analysis, participants were split into high (12 participants with multiple glances toward the irrelevant stimuli) and low (12 participants with one or no glances toward the stimuli) glance groups. Self-reported driving amount was compared between these two groups. Driving amount ($\bar{x}$ = 1.03, SD = 0.40) was calculated by summing the normalized responses on the two driving exposure questions, which were collected on scales of 4 and 5, respectively. Hence, the resulting combined score had a possible range of 0.45 (i.e., 1/4 + 1/5) to 2 (i.e., 4/4 + 5/5). An exact Wilcoxon test (used to account for ties) found that participants who glanced multiple times (high glance group) reported to drive significantly more than those in the low glance group (Δ = -0.4, W = 33, p = .04).

The two glance groups were compared on their technology exposure, which was scored by averaging responses to self-reported technology experience and willingness to try new technology questions, both collected on 10-point scales. One participant was removed from these survey data obtained during the laboratory experiment as he was observed to be rushing through the survey questions and answered many of them uniformly. An exact Wilcoxon test found that the high glance group (N = 11, $\bar{x}$ = 8.64, SD = 1.14) had a significantly larger technology exposure rating than the low glance group (N = 12, $\bar{x}$ = 7.33, SD = 1.44), Δ = -1.25, W = 31, p = .03. It is possible that drivers with more experience with technology and driving are more comfortable handling the cognitive load of the driving task, and therefore glance more often at the distraction because they have more spare capacity.

Apart from driving experience and technology exposure, two self-reported measures of attention that may be relevant to involuntary distraction behaviour were examined: the involuntary subscales from the revised SDDQ and the everyday distractibility scale from CFQ. Variability in SDDQ subscale scores indicate that individual differences were captured by these subscales

(Appendix T). Participants' SDDQ involuntary subscale scores were treated as interval data, since the scales are made up of more than four Likert-type items that are combined into a composite score (Boone & Boone, 2012). Participants' aggregated (averaged) Involuntary 1 (difficulty ignoring distractions) and Involuntary 2 (looking away for longer than intended) sections scores ($\bar{x}$ = 2.5, SD = 0.5) ranged between 1.6 and 3.5 (the possible range was 1 to 5). Linear regression models found participants in the high glance group had a marginally greater average mean score for the aggregated Involuntary 1 and Involuntary 2 subscales (Δ = 0.37, 95% CI: -.04, .79, *p* = .08). However, there were no significant relationships between the mean scores of the individual sections and glance group, nor were the SDDQ involuntary scores significantly correlated with participants' glance metrics (Appendix T).

Participants' CFQ scales were also treated as interval data, since the scales are made up of over four Likert-type items that are combined into a composite score (Boone & Boone, 2012). Participants CFQ scores ($\bar{x}$ = 13.5, SD = 3.2) ranged from 8 to 19 (possible score values range from 0 to 32). CFQ scores were strongly correlated with participants' average glance durations (excluding 0s), where higher CFQ scores (indicating increased cognitive failures) were associated with longer glance durations (r(13) = .64, *p* = .01, Figure 27). None of the other glance metrics were significantly correlated with CFQ scores (Table 6) and there was no significant difference between the CFQ scores of high and low glance groups (*F*(1, 21) = 0.46, *p* = .50).

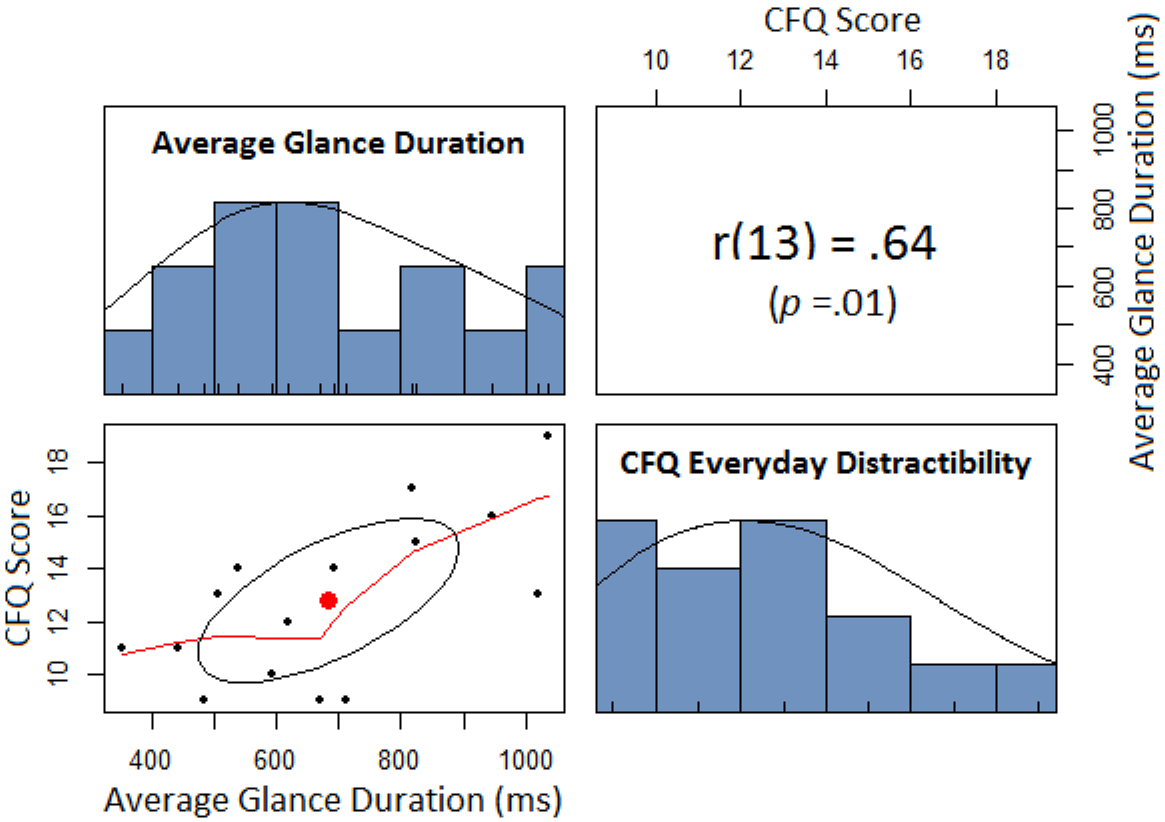


Figure 27: Correlation between participants' average glance durations toward the involuntary distraction and their CFQ scores

Table 6: Correlations between glance metrics for participants who glanced toward the involuntary distraction and their CFQ scores

	Correlation coefficient with CFQ	*p*
Number of glances (Spearman)	r(13) = .05	.85
Total duration of glances (Pearson)	r(13) =.23	.40
Average duration of glances (Pearson)	r(13) =.64	.01
Average glance initiation time (Pearson)	r(13) =.01	.96

Further analysis was conducted at the stimulus level (i.e., with repeated measures for the high glance group) using linear mixed-effect models with logarithmic transforms to correct for modelling assumptions. A one point increase in CFQ score was significantly related to a 6% increase in glance duration (95% CI: 2, 11). A one point increase in CFQ score was marginally significantly related to a 7% increase in total duration of glances to a stimulus (95% CI: -1, 15, *p*

= .08). CFQ score was not significantly related to glance initiation time (*F*(1, 13) = 0.94, *p* = .35).

4.6.1.3 Effects of individual differences in cognitive task performance

Participants' Stroop (Appendix U) and flanker task scores (Appendix V) were not significantly correlated with their distraction engagement metrics and them being in high or low glance groups.

4.6.1.4 Post-drive urban and rural distractor ratings

Participants' ratings of how distracting the irrelevant stimuli were in the urban and rural environments were not a good reflection of their glance behaviours (Appendix W). Only one marginally significant relationship was identified: participants, who rated the urban environment stimuli as more distracting than other participants, had faster glance initiation times in the urban environment as well (F(1, 13) = 3.64, *p* = .08).

It was hypothesized that the RHL_{FCE} may be related to differences in how much participants engaged with the distraction between the urban (high load) and rural (low load) driving environments. No significant effects were found in relation to simulator performance (Appendix X). However, participants with larger RHL_{FCE} (i.e., individuals who are affected more by changes in perceptual load) rated the stimulus as being more distracting in the rural environment than in the urban environment (r(22) = .36, *p* = .08).

4.6.2 Lead vehicle braking events

Linear mixed models were used to analyze the lead vehicle braking event metrics defined earlier in Table 4. Descriptive statistics for these metrics are reported in Appendix Y.

Logarithmic transforms were used for all the dependent variables to meet normality assumptions. The independent variables were distraction type and driving environment, participant was treated as a random factor. The gap time at lead vehicle brake onset and its interactions with other factors were used as covariates. Non-significant interactions were removed from the final models. Table 7 provides a summary of the F-statistics of the final models.

It should be noted that through a linear mixed model, it was found that gap time did not differ based on distraction type (*F*(1, 70) = 0.02, *p* = .88), environment (*F*(1, 70) = 0.42, *p* = .52), and their interaction (*F*(1, 69) = 0.002, *p* = .95).

Table 7: Lead vehicle braking event statistical modeling results for Experiment 2. More detailed results showing removed interaction terms may be found in Appendix Z

	Gap time		**Distraction**		**Environment**		**Distraction X Environment**		**Gap Time X Environment**	
Response variable	F-value	*p*	F-value	*p*	F-value	*p*	F-value	*p*	F-value	*p*
ART	F(1,69) = 29.99	<.0001	F(1,69) = 14.39	.0003	F(1,69) = 6.07	.02	-	-	-	-
BTT	F(1,69) = 56.04	<.0001	F(1,69) = 0.08	.78	F(1,69) = 1.62	.21	-	-	-	-
BRT	F(1,68) = 87.10	<.0001	F(1,68) = 12.47	.0007	F(1,68) = 1.70	.20	-	-	F(1,68) = 4.45	.04
TTC_{min}	F(1,67) = 42.36	<.0001	F(1,67) = 13.18	.0005	F(1,67) = 59.55	<.0001	F(1,67) = 7.29	.009	F(1,67) = 15.48	.0002
Maximum deceleration	F(1,68) = 47.21	<.0001	F(1,68) = 2.08	.15	F(1,68) = 17.67	.0001	-	-	F(1,68) = 9.87	.003
PT	F(1,57) = 9.31	.004	F(1,57) = 0.61	.44	F(1,57) = 0.63	.43	-	-	-	-
IT	F(1,68) = 14.28	.0003	F(1,68) = 4.75	.03	F(1,68) = 1.14	.29	-	-	-	-

4.6.2.1 Braking responses

Similar to the findings of the first experiment, participants had delayed ARTs under involuntary distraction: participants were 16% slower to release the accelerator pedal (on average) in response to lead vehicle braking (95% CI: 7, 25, *p* = .0003) (Figure 28). Further, ART was also greater in the rural environment compared to the urban one: participants were 9% faster at releasing the accelerator pedal in the urban condition than in the rural condition (95% CI: 2, 16, *p* = .02).

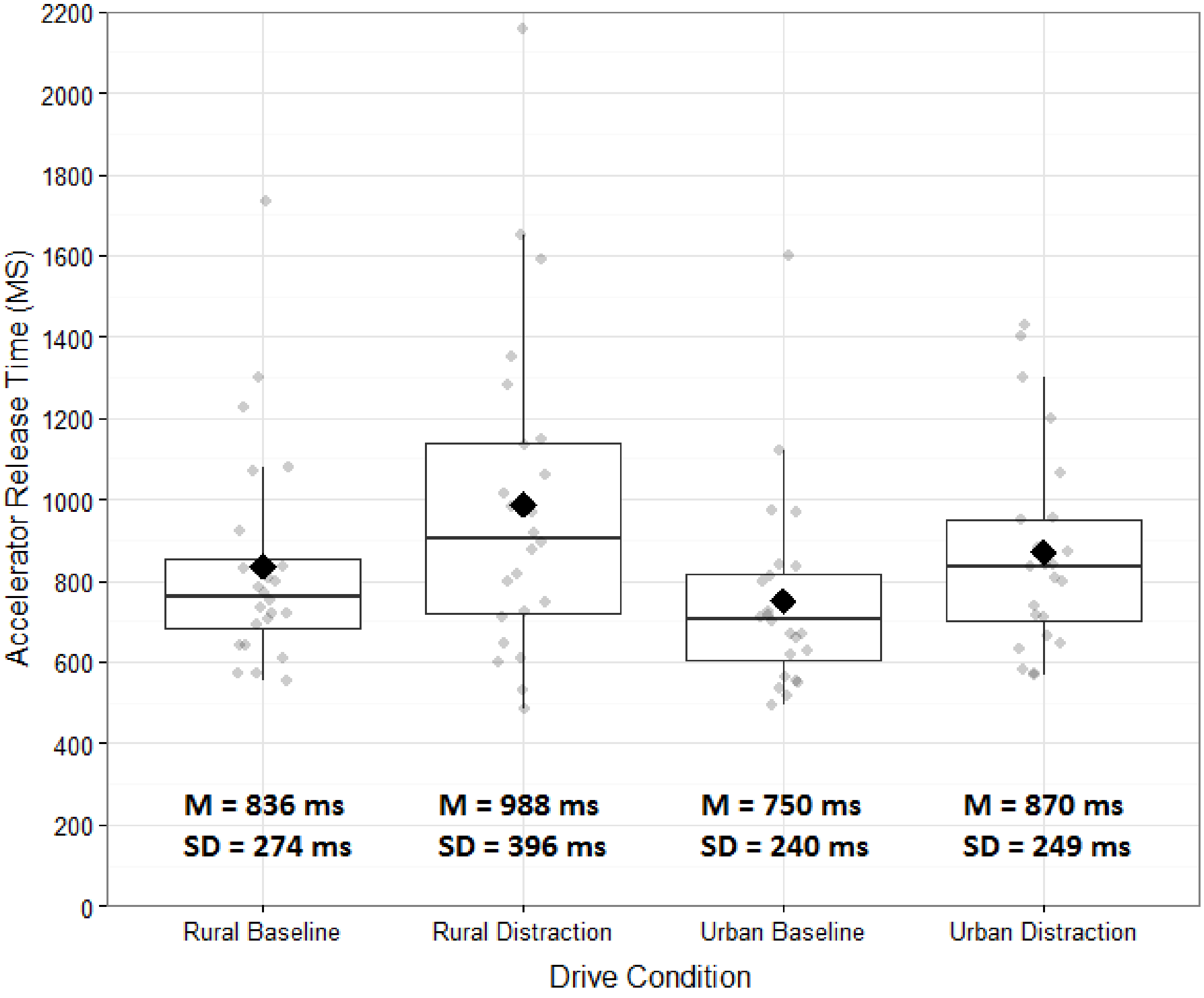


Figure 28: Boxplots of average ARTs in Experiment 2

Since there was no significant effect on BTT (*p* = .78, Table 7), BRT was delayed overall: participants were 10% slower to brake under distraction (95% CI: 4, 15, *p* = .0007). In the urban environment, every one second increase in gap time at the lead vehicle brake onset was associated with a 24% increase in BRT (95% CI: 17, 30, *p* <.0001), while in the rural environment, it was associated with a 30% increase in BRT (95% CI: 23, 38, *p* <.0001).

4.6.2.2 Perception response times

There was no effect on perception time under distraction (*p* = .44, Table 7), but inspection times were 16% longer (95% CI: 1, 32, *p* = .03).

4.6.2.3 Minimum time to collision

A significant interaction effect was found between distraction type and driving environment. For the rural environment, involuntary distractions led to 15% shorter TTC_{min} compared to the baseline condition (95% CI: 7, 22, $p = .001$). A similar effect was not observed for the urban environment ($p = .99$) but TTC_{min} was already 50% shorter in the urban baseline condition than the rural baseline condition (95% CI: 40, 63, $p <.0001$). In the urban environment, every one second increase in gap time at the lead vehicle brake onset was associated with a 38% increase in TTC_{min} (95% CI: 28, 49, $p <.0001$), while in the rural environment, it was associated with a 23% increase in TTC_{min} (95% CI: 16, 31, $p <.0001$).

4.6.2.4 Maximum deceleration

Maximum deceleration was not related to distraction type, but to driving environment. On average, participants had a 29% larger maximum deceleration in the urban environment than in the rural environment (95% CI: 15, 46, $p = .0001$). In the urban environment, every one second increase in gap time at the lead vehicle brake onset was associated with a 20% decrease in maximum deceleration (95% CI: 17, 24, $p <.0001$), while in the rural environment, it was associated with a 15% increase in maximum deceleration (95% CI: 11, 19, $p <.0001$).

4.6.2.5 The effects of individual differences in inhibition, as measured by glance behaviours, on driving performance metrics

Participants who exhibited higher inhibition towards involuntary distraction in the simulator (that is who were in the low glance group) did not drive differently than those who were in the high glance group.

4.6.3 Non-braking-event driving

Linear mixed-effects models with participant as a random factor were used to determine if there were significant effects on driving metrics collected outside of lead vehicle braking events. These metrics, introduced earlier, include SDLP, average absolute deviation from the target speed, speed variability, and average speed. Logarithmic transforms were applied to the first three to meet the normality assumption. Similar to earlier analysis, non-significant interactions terms were dropped from final models (Table 8).

Table 8: Experiment 2 modelling results for driving performance metrics collected outside of lead vehicle braking events

	Distraction type		**Environment**	
Response variable	F-value	p	F-value	p
SDLP	F(1,70) = 0.78	.38	F(1,70) = 12.90	.0006
Average absolute deviation from target speed	F(1,70) = 0.004	.95	F(1,70) = 0.003	.95
Speed variability	F(1,70) = 0.72	.40	F(1,70) = 5.76	.02

4.6.3.1 Standard deviation of lane position

When driving through the urban environment ($\bar{x}$ = 0.54 ft, SD = 0.16 ft), participants had 33% greater SDLP (95% CI: 14, 57, p = .0006) than they did in the rural environment ($\bar{x}$ = 0.44 ft, SD = 0.24 ft).

4.6.3.2 Speed variability

Since participants were instructed to maintain specific speeds, their average absolute deviation from the target speed (50 mph in the rural environment and 35 mph in the urban environment) was analyzed. No effects were observed (Table 8). Participants' speed variability was 23% larger (95% CI: 4, 45, p = .02) in the urban environment ($\bar{x}$ = 1.50 mph, SD = 0.84 mph) compared to the rural environment ($\bar{x}$ = 1.18 mph, SD = 0.59 mph).

4.6.3.3 Average speed

In the rural environment, average speed was related to distraction condition (F(1, 23) = 6.12, p = .02). Average rural speeds under distractions ($\bar{x}$ = 49.86 mph, SD = 1.51 mph) were 0.79 mph (95% CI: 0.13, 1.45, p = .02) slower than they were without distractions ($\bar{x}$ = 50.65 mph, SD = 1.95 mph). For the urban environment, distraction type did not have an effect on average speed (F(1, 23) = 1.83, p = .19) and thus there was no significant difference between average speeds in the distraction condition ($\bar{x}$ = 35.50 mph, SD = 1.16 mph) and the baseline ($\bar{x}$ = 35.05 mph, SD = 1.17 mph).

4.6.3.4 Non-braking-event driving under distraction: comparing driving metrics between participants who glanced and those who did not

No difference was found between participants' non-braking-event driving performance (i.e., no lead vehicle braking section) with respect to whether or not the participant glanced at the stimulus in the region of interest.

4.7 Discussion

Participants engaged with the involuntary distraction in Experiment 2 similarly to how they did in Experiment 1. In Experiment 1, there were 0.47 glances per subject per stimulus, and overall participants glanced toward 36% of all stimuli presented (143 of 396). In this experiment (Experiment 2), there were 0.54 glances per subject per stimulus, and overall participants glanced toward 40% of all stimuli presented (77 of 192). As mentioned previously in section 3.6, these rates, when compared to findings from studies on roadside advertisements, indicate that the experimental stimuli utilized in these two experiments may be less distracting than roadside advertisments. This is expected because these experimental stimuli were designed to have minimal content in order to control the relevancy of the distraction. Further experimentation would be needed to identify if more distracting involuntary distractions (varying the capture power) would affect driving performance or individual differences in suceptibility to involuntary distraction.

Similar to the findings of the first experiment, participants had delayed ARTs under involuntary distraction: participants were 16% slower to release the accelerator pedal (on average) in response to lead vehicle braking (95% CI: 7, 25) compared to driving without distraction. Further, ART was also greater in the rural environment compared to the urban one: participants were 9% faster at releasing the accelerator pedal in the urban condition than in the rural condition (95% CI: 2, 16). Since there was no significant effect on BTT (p = .78), BRT was delayed overall: participants were 10% slower to brake under distraction (95% CI: 4, 15). These delays appear to be a result of slower processing or lack of perceived urgency instead of a visual delay in seeing brake onset as there was no effect on perception time under distraction (p = .44), but inspection times were 16% longer (95% CI: 1, 32) compared to baseline driving. For the rural environment, involuntary distractions led to 15% shorter TTC_{min} compared to the baseline condition (95% CI: 7, 22). A similar effect was not observed for the urban environment, likely due to the faster ARTs and higher maximum decelerations observed in this environment in general.

Participants had greater SDLPs and speed in the urban environment compared to the rural environment. Different roadside furniture (e.g., guardrails, no guardrails) can affect the lateral position the driver chooses to adopt (Bella, 2013) and hence the variety of roadside configurations employed in the urban scenario may have induced larger SDLP. There may have been greater speed variability in the urban environment because drivers use environmental cues from traffic scenes to adjust their speed (Charlton et al., 2010).

Contrary to what was hypothesized, perceptual load imposed through the environmental condition had no effect on glances to the irrelevant stimuli and there were no significant relation between these glances and cognitive task measures. However, self-reported everyday distractibility as measured through the Cognitive Failures Questionnaire was correlated with length of glances towards the irrelevant stimuli ($r(13) = .64$, $p = .01$). Drivers who glanced multiple times at the irrelevant stimuli were more frequent drivers who drove longer distances in the previous year ($W = 33$, $p = .03$) and self-reported more technology experience and greater willingness to try new technology ($W = 31.5$, $p = .04$) than participants who only glanced once or not at all. Participants with multiple glances also had marginally higher mean scores on the revised SDDQ Involuntary distraction items ($\Delta = 0.37$, 95% CI: -.04, .79, $p = .08$) than those who glanced once or not at all.

Chapter 5

5.0 Discussion

5.1 Involuntary versus voluntary distraction

The evidence compiled from Experiments 1 and 2 shows that involuntary and voluntary distraction affect driving performance, and that these effects are different. It appears that drivers are cognisant of their (voluntary) distraction when intentionally engaging in a secondary task and thus compensate for their accelerator release delays in lead vehicle braking responses by transitioning more quickly to the brake pedal. In contrast, drivers appear to be less cognisant of involuntary distraction effects. These preliminary findings about involuntary distraction should be explored through further experimentation both in the simulator and on the road, under varying perceptual and cognitive loads.

It should be noted that the tasks used in the first experiment did not just differ by being voluntary and involuntary. The voluntary task was a visual-manual task and afforded a much greater amount of engagement than the audiovisual involuntary task. Although the tasks were different, they produced very similar ART delay effects in lead vehicle braking events, making their comparison relevant. Interestingly, participants did not respond to these delays in the same way under the different distraction conditions.

5.2 Involuntary distraction engagement under varying perceptual loads

It is surprising that environmental condition, which was designed to impose two levels of perceptual load on drivers, did not have a greater impact on the extent to which participants engaged with the involuntary distraction stimuli in the simulator. Literature shows that how a distractor is processed depends on the type and the extent of mental processes that are being claimed (Forster & Lavie, 2008; Lavie et al., 2004). In general, increasing perceptual load for processing task-relevant stimuli decreases distractor interference, because there is less attentional capacity remaining to automatically process task-irrelevant stimuli (Forster & Lavie, 2008; Lavie, 2005). In the current work, the involuntary distractions were displayed on a secondary screen spatially separated from the screens that displayed driving-relevant information (e.g., the dashboard). It was expected that this separation would have enhanced participants' abilities to inhibit the distraction in the urban environment since the spatial attention window narrows around the target space under high perceptual loads (Lavie, 2005). However, no such effects were observed in Experiment 2.

One potential reason for this lack of significance is the use of a bimodal distraction (i.e., visual animation and chime), which might have reduced the effect of perceptual load. The bimodal distraction was chosen since it was effective in capturing and re-orientating participants' attention. However, it has been cited in other literature that higher perceptual load does not always have the expected effect of helping individuals suppress irrelevant stimuli if the distractor is aural and the task is visual (Tellinghuisen & Nowak, 2003). Experiments performed by Santangelo and Spence (2007) showed that visual, auditory, and audiovisual (bimodal) task-irrelevant cues all captured attention in a no perceptual load condition. However, only the bimodal cues captured attention in a high-load condition, indicating that a multi-sensory stimulus can have a stronger effect in disengaging spatial attention. Another plausible explanation is that the mechanism that prioritizes stimuli processing opted to ignore the visual clutter in the urban environment (e.g., scenery) in favour of processing the involuntary distraction stimulus.

5.3 Modulating voluntary distraction with respect to driving demands

Although previous literature has observed drivers not being strategic in how they engage with distractions (Horrey & Lesch, 2009), in Experiment 1, participants were observed modulating their glances to the secondary task based on the driving demands. In non-event driving, both the high self-reported distraction engagement (SRDE) and the low SRDE group showed high glance rates (glances per minute): high (M = 14.2, SD = 6.5), low (M = 7.2, SD = 6.3). These rates were lower during lead vehicle braking events: high (M = 6.5, SD = 3.1), low (M = 3.5, SD = 1.9). During left-turn gap acceptance where participants needed to make a tactical driving decision, the high SRDE group appeared to have modulated their glance rates even further: (M = 4.1, SD = 5.0), while the low SRDE group's glance rates were similar to their rates during lead vehicle braking (M = 3.2, SD = 4.7). Due to the fixed location of these events, these results may be confounded by order effects; however these results call for further research in understanding how drivers choose to modulate their task engagement based on driving demands.

5.4 Driving performance under involuntary distraction

This thesis also aimed to examine the degree to which involuntary attention to irrelevant stimuli may affect drivers' performance. Studying involuntary distractions is particularly important as more salient types of content and displays enter the car ecosystem. A better understanding of involuntary distraction can help designers mitigate the negative effects their designs may unintentionally impose on drivers.

In Experiments 1 and 2, participants had delayed ARTs under involuntary distraction. In Experiment 1, participants were 19% slower (95% CI: 3, 39) to release the accelerator pedal (on average) in response to lead vehicle braking. A similar effect size was observed in Experiment 2, where participants were 16% slower (95% CI: 7, 25) to release the accelerator pedal (on average) in response to lead vehicle braking. Further, in Experiment 2 where driving environment was also a variable of interest, ART was greater in the rural environment compared to the urban one: participants were 9% faster at releasing the accelerator pedal in the urban condition than in the rural condition (95% CI: 2, 16). In both Experiments 1 and 2, there was no significant effect of involuntary distraction on BTT ($p = .78$), which led to BRT being delayed overall in Experiment 2: participants were 10% slower to brake under distraction (95% CI: 4, 15), but not in Experiment 1. The ART delays appear to be a result of slower processing or lack of perceived urgency instead of a visual delay in seeing lead vehicle brake onset as there was no effect on perception time under involuntary distraction in Experiment 1, nor Experiment 2, but inspection times were 30% longer in Experiment 1 (95% CI: 11, 54) and 16% longer (95% CI: 1, 32) in Experiment 2. In Experiment 1, ART delays due to involuntary distractions led to 12% shorter TTC_{min} (95% CI: 1, 21), but in Experiment 2 shorter TTC_{min} was only observed in the rural environment, where involuntary distractions led to 15% shorter TTC_{min} compared to the baseline condition (95% CI: 7, 22). A similar effect was not observed for the urban environment, likely due to the shorter ARTs and higher maximum decelerations observed in this environment in general. Higher maximum decelerations may have been due to the participants having felt a greater urgency to brake in the urban environment: at similar gap times, the slower urban lead vehicle appeared much closer to the participants than the faster rural lead vehicle.

5.5 Driving performance under voluntary distraction

Under voluntary distraction (Experiment 1 only), participants also exhibited ART delays (23% slower than baseline). However, there was a marginally significant decrease in their transition time from the accelerator to the brake pedal (i.e., “brake transition time” or BTT), a potential compensatory mechanism, which led to TTC_{min} values comparable to the baseline condition (instead of the shortened TTC_{min} values observed under involuntary distraction in Experiment 1 and in the rural region of Experiment 2). In contrast to involuntary distraction, participants might have been more conscious of the potential negative effect of distraction, or perceived more urgency to respond to lead vehicle braking, when they voluntarily engaged in distraction behaviours. There is evidence in the literature that drivers exhibit compensatory behaviours when performing secondary tasks (Strayer & Drews, 2004; Young et al., 2007), and increased brake transition times have been observed previously in braking response under non-self-paced (externally paced) secondary tasks (D'Addario, 2014; Donmez et al., 2006). These coping mechanisms can act as a buffer for responding to unpredictable events but may be inadequate at times (e.g., Strayer et al., 2003). Coping mechanisms were observed in Experiment 1 for lead vehicle braking events under voluntary distractions (rapid transition times to the brake pedal after a delayed release of the accelerator) but not under involuntary distractions. A similar trend was observed in Experiment 2, which indicates that drivers may be more conscious of the potential ramifications of distraction when they voluntarily engage in it.

5.6 Distraction engagement in the simulator versus demographics and self-reported cognitive abilities

The analysis from Experiment 1 found that self-reported distraction engagement (SRDE) was a good predictor of voluntary distraction engagement in simulated driving. Individuals with higher levels of self-reported distraction engagement glanced at an in-vehicle display more often, and in total for a larger portion of time during a drive, than those with lower levels of self-reported distraction engagement. Participants from the high engagement group also completed more tasks than the low engagement group (marginally significant). Together, these findings provide evidence supporting the validity of the self-report engagement frequency measures collected using SDDQ as a measure of actual distraction engagement while driving.

As shown in Experiment 2, the differences in participants' glance behaviours towards the irrelevant stimuli were best reflected in their responses to everyday distractibility, as measured by the Cognitive Failures Questionnaire, CFQ. Participants with multiple glances also had marginally higher mean scores on the revised SDDQ Involuntary distraction items ($\Delta = 0.37$, 95% CI: -.04, .79, $p = .08$), indicating greater difficulty ignoring distractions and higher frequency of looking away from the road for longer than intended, than those who glanced once or not at all. This weak effect may be because of sample size, or because involuntary distraction captures attention automatically and unconsciously (Theeuwes & Godijn, 2001; Irwin, Colcombe, Kramer, & Hahn, 2000), and thus the participants may not have been aware of their susceptibility to involuntary distractions. CFQ scores (using the entire CFQ, not just the subsection used in Experiment 2) have been related to lower inhibition of prepotent responses and higher resistance to distraction interference in the past (Friedman & Miyake, 2004). It is possible that the CFQ scores were more reflective of involuntary distraction engagement than the revised SDDQ because the CFQ items explicitly provide consequences associated with distractions. In other words, while people may not remember being distracted, they may better recall the consequences experienced.

The weak effect between the SDDQ measures and distraction engagement in the simulator may be due to incorrectly assuming it is appropriate to treat the SDDQ scales as equal interval scales in order to use parametric statistical tests. However, this assumption was made because the SDDQ metrics use standard Likert scale wording (Marulanda et al., 2015b) and it has been argued that parametric tests may be used on normally distributed Likert data (Norman, 2010) and on Likert scales that are made up of four or more Likert-type items (Boone & Boone, 2012). It is important to acknowledge that the Likert scale results are limited: they do not allow for further inferences about the differences in the underlying characteristics reflected in these values (e.g., the meaning of a 0.37 difference in the involuntary subscale between glance groups).

Participants who glanced multiple times toward the involuntary distraction self-reported more frequent driving, driving longer distances, more technology experience, and greater willingness to adopt new technologies. It is possible that drivers with more experience with technology and driving are more comfortable handling the cognitive load of the driving task in the presence of a distraction, and therefore glanced more often at the distraction because they had more spare capacity.

5.7 Distraction engagement in the simulator versus cognitive task measurements

No significant relationships were found between Stroop task performance and the distraction engagement metrics. The lack of significance may simply be due to a lack of statistical power, but it is also possible that the Stroop performance is not a good predictor of a peripheral distraction task. The spatial co-location of target and distractor can change the effect of the distractor on performance (Lavie, 2005), because when more attention is paid to the target, it must also be paid to the co-located distractor.

It was expected that a greater flanker compatibility effect would be related to greater distraction engagement in the simulator, but such a relationship was not observed. It is possible that engagement with an irrelevant stimulus and performance in the flanker task are not related because the flanker task does not have a distractor that is truly irrelevant to the task. Although the flanker (i.e., the distractor in the task) location is irrelevant, its identity is associated with one of the target responses (Forster & Lavie, 2008). Thus, the flanker paradigm may not be analogous to this experiment’s implementation of involuntary distraction in driving. In future work, it may be worthwhile to explore the alternative task that Foster and Lavie (2008) developed, which uses a distractor that is neither associated with the target response nor the target position. In addition, since the participants were generally young, it is possible that the flanker task was not able to differentiate their inhibition abilities.

Chapter 6

6.0 Conclusion

6.1 Contributions

Overall, the results from these experiments suggest that involuntary and voluntary distraction affect driving performance, and that these effects are different. It appears that drivers are cognisant of their distraction when intentionally engaging with a secondary task and thus compensate for their accelerator release delays by transitioning more quickly to the brake pedal (Experiment 1). In contrast, drivers appear to be less cognisant of involuntary distraction effects. This lack of awareness is mirrored in the findings that while self-reported metrics on frequency of engagement are related to how much participants exhibit voluntary distraction (Experiment 1), self-reported metrics on involuntary distraction engagement are not strongly related to how much participants exhibit involuntary distraction unless there is a consequence to the distraction that drivers may remember and can report on (Experiment 2). These preliminary findings about involuntary distraction should be explored through further experimentation both in the simulator and on the road, under varying perceptual and cognitive loads. Studying involuntary distractions is particularly important as more salient types of content and displays enter the car ecosystem. A better understanding of involuntary distraction can help designers mitigate the negative effects their designs may unintentionally impose on drivers.

With respect to finding the facilitators of driver distraction, SDDQ appears to be a useful tool for measuring susceptibility to voluntary distraction. However, the findings from both Experiment 1 and Experiment 2 suggest that further improvements to the involuntary distraction scale may be necessary; although the involuntary section of SDDQ did not significantly relate to involuntary distraction engagement in the simulator, the marginal relationship between increased number of glances toward the irrelevant stimuli and increased revised SDDQ involuntary mean scores show improvements have been made with the revision. However, CFQ had a significant relationship to involuntary distraction engagement in the simulator, suggesting that CFQ may be better able to capture involuntary distraction. The CFQ questions associate each distractibility item with a particular consequence or context. Including consequences may facilitate drivers’ responses, as drivers may remember the consequence better than the state of being involuntarily distracted.

Thus, further improvements to SDDQ may include structuring the involuntary distraction items to resemble the structure of CFQ.

Perceptual load did not affect drivers' involuntary distraction engagement. Load theory states that perception is an automatic process that proceeds automatically on all stimuli within its capacity. In tasks with low perceptual load, excess perceptual capacity not used by the task may process task-irrelevant distractors, but under high perceptual load tasks, distractor processing is prevented because perceptual load capacity is exhausted. High perceptual load has been shown in laboratory studies to decrease distractor interference from peripheral task-irrelevant stimuli (Forster & Lavie, 2008; Lavie et al., 2004). However, in this work, when perceptual load was varied in the driving environment, no effect was observed on participants' engagement with the irrelevant stimuli while driving. The lack of effect observed may be a result of the stimuli design, since bimodal stimuli may be more powerful at capturing attention than a single mode distraction and thus the effect of perceptual load on distraction interference is reduced (Santangelo & Spence, 2007; Tellinghuisen & Nowak, 2003). However, it may also be that Load Theory is not applicable in complex applied settings such as the driving task.

6.2 Research Limitations

Both Experiment 1 and 2 were conducted in a fixed-base driving simulator. As with all driving simulator studies, there is concern regarding the validity and applicability of the results to real on-road driving situations. Since participants were unable to feel motion feedback for acceleration, deceleration, and steering inputs, the degree of any of these inputs may have been altered from how they would normally drive in their own vehicle. In addition, the perceived urgency of driving events may have been reduced due to the minimal consequences of being involved in a collision during simulated driving. Ideally, similar events would be tested in on-road studies to collect more realistic data; however, due to ethical limitations, experimenters may be unable to recreate these simulated driving events exactly in on-road studies.

Both Experiment 1 and 2 driving simulator studies were part of larger studies, and in these studies participants filled out a questionnaire which asked them explicitly about driver distraction. Thus, it was not considered necessary to request ethical approval to deceive participants about the nature of the experiment. Since participants were informed that the aims of the experiments were to understand driver behaviour under the presence of distracting conditions, they may have been primed to interact differently with the distractions in front of the experimenters than they would have if driving as they normally would.

In addition, it is not specified in the standards (SAE J2944, 2015) how much driving distance or time should be sampled to obtain valid representations of participants' standard deviation of lane position or speed metrics. The regions sampled in these experiments may not have been sufficient to provide quality SDLP and speed metrics: the smallest region used was a 851 ft (16.6 seconds when driving at 35 mph) sample (region 2 in Experiment 1) for data collected at 60 Hz. Similar or smaller samples have been used in literature to compute standard deviation of lane position and mean speed metrics (e.g., Chattington et al. (2009) calculated standard deviation of lateral lane position and mean speeds over 328 ft regions at 30 mph, approximately 7.5 seconds with data collected at 20 Hz).

A limitation that needs to be considered, especially for Experiment 1 is the manual coding of glance information from video data captured from the Surface Pro 2. The camera on this device operates at 30 Hz; therefore, the smallest time step detectable from the video data was 33.3 ms. This time step serves as a lower bound for glance durations and response times to stimuli. The results of the glance analyses, especially those with durations in the 100 ms range, should be interpreted in light of this limitation.

With respect to recruitment of participants, since participants mostly responded to ads sent out around the city, the sample is likely biased. Further, those people who chose to take part in the study may have different characteristics from those who chose not to participate. In addition, only one age group was studied in these experiments, and novice drivers were not studied, so it may not be accurate to apply the findings from this study on other ages and driving experience levels. Finally, although fatigue was monitored throughout both simulator studies, due to both Experiment 1 and Experiment 2 being run as part of larger experiments that required participants to fill out long surveys and perform extra cognitive tasks, it is likely participants experienced fatigue while driving.

6.3 Future Research

Future research should investigate why participants show compensation behaviour under voluntary distractions but not involuntary distractions. In particular, it is not clear whether participants consciously compensate and whether they feel more urgency during voluntary distractions. It may be useful to directly ask participants about their strategies for engaging with, or inhibiting, distractions. The effects of perceptual load on involuntary distraction should also be further studied, for example, by using a unimodal stimulus. Further, it would be interesting to explore whether the revised task proposed by Forster and Lavie (2008) discussed earlier is more suitable to study involuntary driver distraction than the flanker task.

It may be interesting to design an experiment to observe further how voluntary distraction engagement varies with driving context, e.g., driving scenarios that impose high vs. low cognitive loads. It may also be interesting to observe how voluntary and involuntary distraction effects vary between different age groups and driving experience levels. Future experiments would benefit from using tasks which only differ along distraction type and are more similar with respect to task time and modality. A shorter experiment run-time would also be desirable, since longer experiments are unappealing to participants from a scheduling perspective, and are more likely to fatigue participants.

In addition, SDDQ should be modified to increase its sensitivity in detecting the role of inhibition and attentional failures in driving. In this regard, it might be worth incorporating consequences associated with distractions within this section as is done in CFQ, which was found to be a better predictor of involuntary distraction engagement in simulated driving.

References

Ady, R. (1967). An investigation of the relationship between illuminated advertising signs and expressway accidents. *Traffic Safety Research Review*, *11*(3), 9–11.

Ajzen, I. (1991). The Theory of Planned Behavior. *Organizational Behavior and Human Decision Processes*, *50*(2), 179–211.

Alexander, J., Barham, P., & Black, I. (2002). Factors influencing the probability of an incident at a junction: Results from an interactive driving simulator. *Accident Analysis & Prevention*, *34*(6), 779–792.

Allahyari, T., Saraji, G. N., Adl, J., Hosseini, M., Iravani, M., Younesian, M., & Kass, S. J. (2008). Cognitive failures, driving errors and driving accidents. *International Journal of Occupational Safety and Ergonomics*, *14*(2), 149–158.

Alosco, M. L., Spitznagel, M. B., Fischer, K. H., Miller, L. A., Pillai, V., Hughes, J., & Gunstad, J. (2012). Both texting and eating are associated with impaired simulated driving performance. *Traffic Injury Prevention*, *13*(5), 468–75.

Arthur, W., & Doverspike, D. (1992). Locus of control and auditory selective attention as predictors of driving accident involvement: A comparative longitudinal investigation. *Journal of Safety Research*, *23*(2), 73–80.

Beanland, V., Fitzharris, M., Young, K. L., & Lenné, M. G. (2013). Driver inattention and driver distraction in serious casualty crashes: Data from the Australian national crash in-depth study. *Accident; Analysis and Prevention*, *54*(213), 99–107.

Beijer, D., Smiley, A., & Eizenman, M. (2004). Observed driver glance behavior at roadside advertising signs. *Transportation Research Record: Journal of the Transportation Research Board*, *1899*(1), 96–103.

Bella, F. (2013). Driver perception of roadside configurations on two-lane rural roads: Effects on speed and lateral placement. *Accident; Analysis and Prevention*, *50*, 251–62.

Bendak, S., & Al-Saleh, K. (2010). The role of roadside advertising signs in distracting drivers. *International Journal of Industrial Ergonomics*, *40*(3), 233–236.

Berg, E. (1948). A simple objective technique for measuring flexibility in thinking. *The Journal of General Psychology*, *39*(15-22), 15–22.

Berlyne, D. E. (1960). Toward a theory of exploratory behavior: II. Arousal potential, perceptual curiosity, and learning. In *Conflict, Arousal, and Curiosity*. (pp. 193–194). New York, NY: McGraw-Hill Book Company.

Bischoff, D. (2007). Developing guidelines for managing driver workload and distraction associated with telematic devices. *SAE Paper*, (07-0082).

Boersema, T., Zwaga, H. J. G., & Adams, A. S. (1989). Conspicuity in realistic scenes: An eye-movement measure. *Applied Ergonomics*, *20*(4), 267–273.

Boone, H. N. J., & Boone, D. a. (2012). Analyzing Likert Data. *Journal of Extension*, *50*(2), 30.

Broadbent, D. E., Cooper, P. F., FitzGerald, P., & Parkes, K. R. (1982). The Cognitive Failures Questionnaire (CFQ) and its correlates. *The British Journal of Clinical Psychology*, *21*(1), 1–16.

Bruce Mehler, Bryan Reimer, Jonathan Dobres, H. M., & Alea Mehler, Daniel Munger, & J. F. C. (2014). *Further evaluation of the effects of a production level "voice-command" interface on driver behavior: replication and a consideration of the significance of training method*. Retrieved from http://agelab.mit.edu/files/MIT_AgeLab_Technical_Report_2014-2_(Voice_Interfaces_Study_II).pdf

Caird, J. K., & Horrey, W. J. (2011). Twelve practical and useful questions about driving simulation. In D. L. Fisher, M. Rizzo, J. Caird, & J. D. Lee (Eds.), *Handbook of Driving Simulation for Engineering, Medicine, and Psychology* (pp. 5–1 – 5–18). Boca Raton, Fl.: CRC Press.

Caird, J. K., Johnston, K. A., Willness, C. R., Asbridge, M., & Steel, P. (2014). A meta-analysis of the effects of texting on driving. *Accident Analysis and Prevention*, *71*, 311–318.

Caird, J. K., Willness, C. R., Steel, P., & Scialfa, C. (2008). A meta-analysis of the effects of cell phones on driver performance. *Accident; Analysis and Prevention*, *40*(4), 1282–93.

Charlton, S. G. (2009). Driving while conversing: Cell phones that distract and passengers who react. *Accident Analysis and Prevention*, *41*(1), 160–73.

Charlton, S. G., Mackie, H. W., Baas, P. H., Hay, K., Menezes, M., & Dixon, C. (2010). Using endemic road features to create self-explaining roads and reduce vehicle speeds. *Accident; Analysis and Prevention*, *42*(6), 1989–98.

Chattington, M., Reed, N., Basacik, D., Flint, A., & Parkes, A. (2009). *Investigating driver distraction: the effects of video and static advertising (published project report PPR409). TRL Limited*. Retrieved January 22, 2015, from http://www.roadsafetyobservatory.com/Evidence/Details/10415

Cherry, E. C. (1953). Some experiments on the recognition of speech, with one and with two ears. *The Journal of the Acoustical Society of America*, *25*(5), 975.

Christensen, R. H. . (2015). *Regression models for ordinal data*. Retrieved from https://cran.r-project.org/web/packages/ordinal/ordinal.pdf

Consiglio, W., Driscoll, P., Witte, M., & Berg, W. P. (2003). Effect of cellular telephone conversations and other potential interference on reaction time in a braking response. *Accident Analysis and Prevention*, *35*(4), 495–500.

Cooper, P. J., & Zheng, Y. (2002). Turning gap acceptance decision-making: the impact of driver distraction. *Journal of Safety Research*, *33*(3), 321–335.

Cooper, P. J., Zheng, Y., Richard, C., Vavrik, J., Heinrichs, B., & Siegmund, G. (2003). The impact of hands-free message reception/response on driving task performance. *Accident Analysis & Prevention*, *35*(1), 23–35.

Cosman, J. D., Lees, M. N., Lee, J. D., Rizzo, M., & Vecera, S. P. (2012). Impaired attentional disengagement in older adults with useful field of view decline. *The Journal of Gerontology. Series B, Psychological Sciences and Social Sciences*, *67*(4), 405–12.

D'Addario, P. (2014). *Perception-response time to emergency roadway hazards and the effect of cognitive distraction*. University of Toronto. Retrieved from http://hfast.mie.utoronto.ca/Publications/D?Addario_Pamela_M_201403_MASc_thesis_final.pdf

Dingus, T. A., Klauer, S. G., Neale, V. L., Petersen, A., Lee, S. E., Sudweeks, J., … Knipling, R. R. (2006). *The 100-car naturalistic driving study, phase II-results of the 100-car field experiment. DOT HS 810 593*. Washington D.C.

Donmez, B., Boyle, L. N., & Lee, J. D. (2006). The impact of distraction mitigation strategies on driving performance. *Human Factors, 48*(4), 785–804.

Donmez, B., Boyle, L. N., & Lee, J. D. (2007). Safety implications of providing real-time feedback to distracted drivers. *Accident; Analysis and Prevention*, *39*(3), 581–90.

Donmez, B., Boyle, L. N., & Lee, J. D. (2010). Differences in off-road glances: Effects on young drivers' performance. *Journal of Transportation Engineering*, *136*(5), 403–409.

Engstrom, J., Victor, T., & Markkula, G. (2013). Attention selection and multitasking in everyday driving: A conceptual model. In M. A. Regan, J. D. Lee, & T. W. Victor (Eds.), *Driver Distraction and Inattention* (pp. 27–54).

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics*, *16*(1), 143–149.

Feng, J., Marulanda, S., & Donmez, B. (2014). Susceptibility to Driver Distraction Questionnaire (SDDQ): development and relation to relevant self-reported measures. In *Proceedings of the Transportation Research Board 93rd Annual Meeting* (Vol. 2423, pp. 26–34). Washington, DC.

Fitch, G. M., Grove, K., Hanowski, R., & Perez, M. (2014). Compensatory behavior of drivers when conversing on a cell phone. *Transportation Research Record*, *2434*, 1–8.

Foley, J. P., Young, R., Angell, L., & Domeyer, J. E. (2013). Towards operationalizing driver distraction. In *Proceedings of the 7th International Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design*.

Forster, S., & Lavie, N. (2008). Failures to ignore entirely irrelevant distractors: The role of load. *Journal of Experimental Psychology. Applied*, *14*(1), 73–83.

Franconeri, S. L., & Simons, D. J. (2003). Moving and looming stimuli capture attention. *Perception & Psychophysics*, *65*(7), 999–1010.

Franconeri, S. L., & Simons, D. J. (2005). The dynamic events that capture visual attention: A reply to Abrams and Christ (2005). *Perception & Psychophysics*, *67*(6), 962–966.

Friedman, N. P., & Miyake, A. (2004). The relations among inhibition and interference control functions: a latent-variable analysis. *Journal of Experimental Psychology: General*, *133*(1), 101–135.

Google Inc. (2013). *SEC Accession No. 0001288776-13-000074*. Retrieved July 4, 2015, from http://www.sec.gov/Archives/edgar/data/1288776/000128877613000074/0001288776-13-000074-index.htm

Haigney, D. E., Taylor, R. G., & Westerman, S. J. (2000). Concurrent mobile (cellular) phone use and driving performance: Task demand characteristics and compensatory processes. *Transportation Research Part F: Traffic Psychology and Behaviour*, *3*(3), 113–121.

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In P. A. Hancock & N. Meshkati (Eds.), *Human Mental Workload*. Amsterdam: North Holland Press.

Ho, G., Scialfa, C. T., Caird, J. K., & Graw, T. (2001). Visual search for traffic signs: The effects of clutter, luminance, and aging. *Human Factors*, *43*(2), 194–207.

Hollingworth, A., Simons, D. J., & Franconeri, S. L. (2010). New objects do not capture attention without a sensory transient. *Attention, Perception & Psychophysics*, *72*(5), 1298–310.

Horberry, T., Anderson, J., Regan, M. A., Triggs, T. J., & Brown, J. (2006). Driver distraction: The effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. *Accident Analysis and Prevention*, *38*(1), 185–191.

Horrey, W. J., & Lesch, M. F. (2008). Factors related to drivers' self-reported willingness to engage in distracting in-vehicle activities. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *52*(19), 1546–1550.

Horrey, W. J., & Lesch, M. F. (2009). Driver-initiated distractions: Examining strategic adaptation for in-vehicle task initiation. *Accident; Analysis and Prevention*, *41*(1), 115–22.

Horrey, W. J., & Wickens, C. (2007). In-vehicle glance duration: Distributions, tails, and model of crash risk. *Transportation Research Record*, *2018*(1), 22–28.

Hughes, P. K., & Cole, B. L. (1986). What attracts attention when driving? *Ergonomics*, *29*(3), 377–91.

Hurwitz, J. B., & Wheatley, D. J. (2002). Using driver performance measures to estimate workload. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 46, pp. 1804–1808). Baltimore, Maryland.

Irwin, D. E., Colcombe, A. M., Kramer, A. F., & Hahn, S. (2000). Attentional and oculomotor capture by onset, luminance and color singletons. *Vision Research*, *40*(10-12), 1443–1458.

Kirchner, W. (1958). Age difference in short-term retention of rapidly changing information. *Journal of Experimental Psychology*, *55*(4), 352–358.

Land, M. F., & Lee, D. N. (1994). Where we look when we steer. *Nature*, *369*(6483), 742–4.

Landry, S. J., Sheridan, T. B., & Yufik, Y. M. (2001). A methodology for studying cognitive groupings in a target-tracking task. *IEEE Transactions on Intelligent Transportation Systems*, *2*(2), 92–100.

Lavie, N. (2005). Distracted and confused?: Selective attention under load. *Trends in Cognitive Sciences*, *9*(2), 75–82.

Lavie, N., Hirst, A., de Fockert, J. W., & Viding, E. (2004). Load theory of selective attention and cognitive control. *Journal of Experimental Psychology. General*, *133*(3), 339–54.

Lee, J., Young, K., & Regan, M. A. (2008). Defining driver distraction. In M. A. Regan, J. Lee, & K. Young (Eds.), *Driver Distraction: Theory, Effects, and Mitigation* (pp. 31–40). CRC Press.

Lerner, N., & Boyd, S. (2005). *On-road study of willingness to engage in distracting tasks (Report No. DOT HS 809 863)*. Washington D.C.

Marulanda, S., Chen, H. Y. W., & Donmez, B. (2015a). Test-retest reliability of the Susceptibility to Driver Distraction Questionnaire (SDDQ). *Transportation Research Record*.

Marulanda, S., Chen, H.-Y. Y. W., & Donmez, B. (2015b). Capturing voluntary, involuntary, and habitual components of driver distraction in a self-reported questionnaire. In *8th International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*. Salt Lake City, UT.

McEvoy, S. P., Stevenson, M. R., & Woodward, M. (2007). The prevalence of, and factors associated with, serious crashes involving a distracting activity. *Accident; Analysis and Prevention*, *39*(3), 475–82.

Metz, B., Schömig, N., & Krüger, H.-P. (2011). Attention during visual secondary tasks in driving: Adaptation to the demands of the driving task. *Transportation Research Part F: Traffic Psychology and Behaviour*, *14*(5), 369–380.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. *Cognitive Psychology*, *41*(1), 49–100.

Moray, N. (1959). Attention in dichotic listening: Affective cues and the influence of instructions. *Quarterly Journal of Experimental Psychology, 11*(1), 56–60.

Mourant, R. R., Rockwell, T. H., & Rackoff, N. J. (1969). Drivers’ eye movements and visual workload. *Highway Research Record*, (292), 1–10.

Moussa, G., Radwan, E., & Hussain, K. (2012). Augmented Reality Vehicle system: Left-turn maneuver study. *Transportation Research Part C: Emerging Technologies, 21*(1), 1–16.

Murphy, P. (2002). Inhibitory control in adults with Attention-Deficit/Hyperactivity Disorder. *Journal of Attention Disorders, 6*(1), 1–4.

National Highway Traffic Safety. (2013). *Distracted Driving 2011* (No. DOT HS 811 737).

National Highway Traffic Safety Administration. (2013). *Visual-manual NHTSA driver distraction guidelines for in-vehicle electronic devices. docket no. NHTSA-2010-0053*.

Retrieved July 4, 2015, from http://www.distraction.gov/downloads/pdfs/visual-manual-nhtsa-driver-distraction-guidelines-for-in-vehicle-electronic-devices.pdf

Norman, G. (2010). Likert scales, levels of measurement and the "laws" of statistics. *Advances in Health Sciences Education*, *15*(5), 625 – 632.

Parkes, A., & Hooijmeijer, V. (2001). Driver situation awareness and carphone use. In *Proceedings of the 1st Human-Centered Transportation Simulation Conference (ISSN 1538- 3288)*. Iowa City.

Parmentier, F. B. R. (2008). Towards a cognitive model of distraction by auditory novelty: The role of involuntary attention capture and semantic processing. *Cognition*, *109*(3), 345–362.

Regan, M. A., Hallett, C., & Gordon, C. P. (2011). Driver distraction and driver inattention: Definition, relationship and taxonomy. *Accident; Analysis and Prevention*, *43*(5), 1771–81.

Regan, M. A., Young, K. L., Lee, J. D., & Gordon, C. P. (2008). Sources of Driver Distraction. In M. A. Regan, J. D. Lee, & K. L. Young (Eds.), *Driver distraction: Theory, effects, and mitigation* (pp. 249–279). CRC Press.

Road vehicles -- ergonomic aspects of transport information and control systems -- occlusion method to assess visual distraction due to the use of in-vehicle information and communication systems (ISO Standard 16673: 2007). (2007). Geneva, Switzerland, Switzerland.

Rogers, R., & Monsell, S. (1995). Costs of a predictible switch between simple cognitive tasks. *Journal of Experimental Psychology*, *124*(2), 207–231.

Roper, Z. Z. J. J., Cosman, J. J. D., & Vecera, S. S. P. (2013). Perceptual load corresponds with factors known to influence visual search. *Journal of Experimental Psychology. Human Perception and Performance*, *39*(5), 1340–51.

SAE International. (2015). *Operational definitions of driving performance measures and statistics: SAE J 2944*. Retrieved from http://standards.sae.org/j2944_201506/

Santangelo, V., & Spence, C. (2007). Multisensory cues capture spatial attention regardless of perceptual load. *Journal of Experimental Psychology. Human Perception and Performance*, *33*(6), 1311–21.

Serafin, C., Wen, C., Paelke, G., & Green, P. (1993). Car phone usability: A human factors laboratory test. In *Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting* (pp. 220–224). Human Factors Society.

Sheridan, T. B. (2004). Driver distraction from a control theory perspective. *Human Factors*, *46*(4), 587–99.

Shinar, D., McDowell, E. D., & Rockwell, T. H. (1977). Eye movements in curve negotiation. *Human Factors*, *19*(1), 63–71.

Strayer, D. L., Cooper, J. M., & Drews, F. A. (2011). Handbook of Driving Simulation for Engineering, Medicine, and Psychology. In D. Fisher, J. Lee, J. Caird, & M. Rizzo (Eds.), .

Strayer, D. L., & Drews, F. A. (2004). Profiles in driver distraction: Effects of cell phone conversations on younger and older drivers. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *46*(4), 640–649.

Strayer, D. L., Drews, F. A., & Johnston, W. A. (2003). Cell phone-induced failures of visual attention during simulated driving. *Journal of Experimental Psychology. Applied*, *9*(1), 23–32.

Stroop, J. (1935). Studies of interference in serial verbal reaction. *Journal of Experimental Psychology*, *18*(6), 643–662.

Tellinghuisen, D. J., & Nowak, E. J. (2003). The inability to ignore auditory distractors as a function of visual task perceptual load. *Perception & Psychophysics*, *65*(5), 817–28.

Tesla Motors. (2015). *Model S*. Retrieved June 26, 2015, from http://www.teslamotors.com/en_CA/models

Theeuwes, J., & Godijn, R. (2001). Attentional and oculomotor capture. In *Attraction, distraction and action - multiple perspectives on attentional capture* (Vol. 133, pp. 121–149). Elsevier.

Trick, L. M., & Enns, J. T. (2009). A two-dimensional framework for understanding the role of attentional selection in driving. In C. Castro (Ed.), *Human Factors of Visual and Cognitive Performance in Driving* (pp. 63–73). Boca Raton, Fl.: CRC Press.

Tsimhoni, O., Smith, C. D., & Green, P. (2003). *On-the-road assessment of driving workload and risk to support the development of an information manager*. Ann Arbor, MI.

Turner, M. L., & Engle, R. W. (1989). Is working memory capacity task dependent? *Journal of Memory and Language*, *28*(2), 127–154.

Victor, T., Dozza, M., Bärgman, J., Boda, C.-N., Engström, J., Flannagan, C., … Markkula, G. (2015). *Analysis of naturalistic driving study data: Safer glances, driver inattention, and crash risk*. Washington D.C. Retrieved from http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_S2-S08A-RW-1.pdf

Wallace, B. (2003). Driver distraction by advertising: Genuine risk or urban myth? In *Proceedings of the Institution of Civil Engineers—Municipal Engineer 156* (pp. 185–190).

Walsh, S. P., White, K. M., Hyde, M. K., & Watson, B. (2008). Dialling and driving: Factors influencing intentions to use a mobile phone while driving. *Accident; Analysis and Prevention*, *40*(6), 1893–900.

White, R., & Fowle, S. (2015). *OnStar AtYourService brings commerce to connected cars*. *GM News*. Retrieved July 4, 2015, from http://media.gm.com/media/us/en/gm/news.detail.html/content/Pages/news/us/en/2015/Jan/0104-atyourservice-gm.html

Wickens, C. D. (2002). Multiple resources and performance prediction. *Theoretical Issues in Ergonomics Science*.

Yan, X., Radwan, E., & Guo, D. (2007). Effects of major-road vehicle speed and driver age and gender on left-turn gap acceptance. *Accident; Analysis And Prevention*, *39*(4), 843–52.

Yantis, S., & Jonides, J. (1990). Abrupt visual onsets and selective attention: Voluntary versus automatic allocation. *Journal of Experimental Psychology. Human Perception and Performance*, *16*(1), 121–34.

Young, K., Regan, M. A., & Hammer, M. (2007). Driver distraction: A review of the literature. In I. J. Faulks, M. A. Regan, M. Stevenson, J. Brown, A. Porter, & J. D. Irwin (Eds.), *Distracted Driving* (pp. 379–405). NSW: Australian College of Road Safety.

Young, M., & Mahfoud, J. (2008). Driven to distraction: Determining the effects of roadside advertising on driver attention. Brunel University. Retrieved from http://bura.brunel.ac.uk/handle/2438/2229

Appendices

Appendix A: Experiment 1 recruitment materials

Mechanical & Industrial Engineering
UNIVERSITY OF TORONTO

Human Factors & Applied Statistics

Participants Needed

For a high-fidelity driving simulator study on driving behavior

Must be ages 25 to 39
Must have normal to corrected vision
Must have a valid G driver's license or equivalent

Location:	Rosebrugh Building (RS) 164 College Street Toronto, ON M5S 3G8
Duration:	approximately 3 hours

Compensation: $50 for entire experiment

Please fill out our screening survey at https://www.surveymonkey.com/s/MRRYTWF so we can assess your eligibility (QR code below). For more information contact us at driverfeedback.hfast@gmail.com

HFASt driving simulator experiment: Call for participants (An invitation email for past participants who indicated they wanted to participate in future experiments)

Hello ____,

The Human Factors and Applied Statistics laboratory at the University of Toronto would like to invite you to participate in a driving simulator experiment at the downtown Toronto campus. We are looking for participants for a driving simulator experiment studying driving behaviors under the presence of different distraction conditions. You will be asked to fill out questionnaires about your driving style, drive the simulator in three different trials, and complete computerized attentional tasks. The entire experiment will take approximately 3 hours and you will be compensated $15/hr plus a $5 dollar bonus for completion of the entire experiment for a total of $50.

We are looking for participants who:

- Have a valid G driver's license or equivalent
- Have normal to corrected vision.
- Are ages 25 and 39.

In order to participate, please take the time to fill out our screening questionnaire so we can assess your eligibility for this experiment: https://www.surveymonkey.com/s/MR9CLNF

If you meet the experiment requirements we will get back to you ASAP to schedule a session at the University of Toronto in downtown Toronto. If you have any questions please contact the researchers at driverfeedback.hfast@gmail.com

Thank you,
Liberty Hoekstra-Atwood and Susana Marulanda
HFASt Laboratory
Mechanical and Industrial Engineering
University of Toronto

Invitation to schedule session for HFASt driving simulator experiment (Scheduling email)

Hello ___,

Thanks for taking the time to fill out our driving experiment screening questionnaire. You are eligible to participate in our driving simulator experiment studying driving behaviors under different distraction conditions. You will be asked to drive the simulator in three different trials, and then complete computerized attentional tasks. The entire experiment will take approximately 3 hours and you will be compensated plus a $5 dollar bonus for completion of the entire experiment for a total of $50.

Please fill out this doodle to indicate which day and time you would like to book your session on: http://doodle.com/kri66wwwewkpgave. Once you do this we can book you for a session at the Rosebrugh Building at 164 College Street, Toronto.

Thank you,
Liberty Hoekstra-Atwood and Susana Marulanda
HFASt Laboratory
Mechanical and Industrial Engineering
University of Toronto

HFASt driving simulator experiment session confirmation (Confirmation email)

Hello ______,

We are writing to confirm your driving experiment session on <<Day>>, <<Month>>, <<Date>>, 2014 at <<Time>>. The experiment will take place at Rosebrugh Building at 164 College Street, Toronto. Please arrive at the entrance of the building: http://map.utoronto.ca/marker/main-entrance-to-the-rosebrugh-building, and one of our researchers will meet you there. We advise taking public transport, but parking is available on campus if needed. If you require corrective lenses, please wear contact lenses to the experiment and try to have good quality sleep the night prior to your session. Let us know if you have any questions.

Thank you,
Liberty Hoekstra-Atwood and Susana Marulanda
HFASt Laboratory
Mechanical and Industrial Engineering
University of Toronto

Thank you for participating in the HFASt driving simulator experiment (Thank you email)

Hello ___,

Thank you for participating in our distracted driving experiment. We appreciate your contribution to the engineering community.

Thank you,
Liberty Hoekstra-Atwood and Susana Marulanda
HFASt Laboratory
Mechanical and Industrial Engineering
University of Toronto

Appendix B: Experiment 1 screening survey

Driving Experiment Screening Questionnaire

You are invited to participate in a driving experiment conducted by the Human Factors and Applied Statistics Lab (Director: Prof. Birsen Donmez) at the Department of Mechanical and Industrial Engineering, University of Toronto. Before you can participate in our driving experiment, you must fill out the below questionnaire so we can determine your eligibility.

The goal of this study is to understand human driving behaviours and make our roads safer. If you choose to participate, you will be presented with questions about yourself and your driving behaviours.

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, separately from the results of the following research survey. Under no circumstances will personal data be revealed to any third party, for any purpose.

If you have any questions or concerns you would like addressed before or after completing this questionnaire, please contact the researchers at driverfeedback.hfast@gmail.com or 416.978.0881.

1. What is your first name?
2. What is your last name?
3. What is your e-mail address?
4. What is your phone number?
5. Choose your preferred method of contact
a. E-mail
b. Phone
c. Either
6. 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).
    a. I am interested in participating in your future research; please contact me when opportunities become available.
7. What is your age?
8. What is your sex?
    a. Male
    b. Female
9. Do you ordinarily wear corrective lenses of any kind?
    a. Yes
    b. No
10. If you do have corrected vision, are you able to wear contact lenses during the experiment?
    a. Yes
    b. No
11. Are you right handed?
    a. Yes

b. No

12. Do you currently hold a valid government issued driver’s license?

a. Yes
b. No

13. What are your current driver’s licenses?

a. Full license (e.g. G license in Ontario)
b. Learner’s license (e.g. G1 and G2 licenses in Ontario)
c. Motorcycle (M, M1, M2 in Ontario)
d. Other licenses please specify ____________________________

14. How often do you drive a motor vehicle?

a. Almost every day
b. A few days a week
c. A few days a month
d. A few days a year or less

15. Over the last year, how many kilometers have you driven?

a. Under 5,000 km
b. Between 5,001 km and 15,000 km
c. Between 15,001 km and 25,000 km
d. Between 25,001 km and 35,000 km
e. Between 35,001 km and 45,000 km
f. Over 45,000 km
g. None
h. I don’t know

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.

16. Have you ever driven in a driving simulator?

a. No, never
b. Once or twice
c. Multiple times
d. Regularly

17. If you have used a driving simulator before, did you ever experience simulator sickness?

a. Yes
b. No

18. Do you frequently experience migraine headaches?

a. Yes
b. No

19. Do you experience motion sickness?

a. Yes
b. No

20. Are you pregnant?

a. Yes
b. No

Appendix C: SDDQ distraction questions

Self-reported distraction questions from the SDDQ (Feng et al., 2014) used in Experiment 1.

Table C1 Self-reported distraction engagement

When driving, I:					
Responses	*Never*	*Rarely*	*Sometimes*	*Often*	*Very Often*
a. have phone conversations					
b. manually interact with a phone (e.g., sending text messages).					
c. adjust the settings of in-vehicle technology (e.g., radio channel or GPS).					
d. read roadside advertisements.					
e. visually dwell on roadside accident scenes if there are any.					
f. chat with passengers if there are any.					

Table C2 Involuntary distraction attributes

While driving, you find it distracting when						
Responses	*Strongly Disagree*	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*	*Never Happens*
a. your phone is ringing.						
b. you receive an alert from your phone (e.g., incoming text message).						
c. you are listening to music.						
d. you are listening to talk radio.						
e. there are roadside advertisements.						
f. there are roadside accident scenes.						
g. a passenger speaks to you.						
h. daydreaming.						

Appendix D: Counterbalanced Experiment 1 orders by SRDE and gender

B = Baseline, V = Voluntary distraction drive, I = Involuntary distraction drive

SRDE Category	**Gender**	**Participant Number**	**Experiment Order**
High	Male	**109**	**BVI**
		114	**IVB**
		119	**BIV**
		121	**VIB**
		126	**IBV**
		131	**VBI**
	Female	**101**	**BIV**
		125	**VIB**
		133	**VBI**
		136	**IBV**
		137	**BVI**
		138	**IVB**
Medium	**Male**	**110**	**VBI**
		111	**IBV**
		112	**IVB**
		113	**VIB**
		116	**BIV**
		117	**BVI**
	Female	**102**	**BVI**
		118	**IVB**
		124	**VBI**
		132	**BIV**
		134	**VIB**
		135	**IBV**
Low	**Male**	**108**	**BVI**
		115	**IBV**
		120	**VIB**
		123	**BIV**
		127	**VBI**
		129	**IVB**
	Female	**103**	**BIV**
		105	**VBI**
		106	**IBV**
		107	**VIB**
		122	**BVI**
		130	**IVB**

Appendix E: Experiment 1 informed consent

Participant Consent Form

Title: Designing feedback to help induce safer driving behaviours

Investigators: Liberty Hoekstra-Atwood (519.807.6848; lha@mie.utoronto.ca)

Maryam Merrikhpour (416.978.0881; maryam.merrikhpour@utoronto.ca)

Susana Marulanda (647.376.3536; smarulan@mie.utoronto.ca)

Jaquelyn Monis Rodriguez (416.978.0881; j.monisrodriguez@mail.utoronto.ca)

Dr. Birsen Donmez (416.978.7399; donmez@mie.utoronto.ca)

You are being asked to take part in a research study. 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 enough about 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 under the presence of distracting conditions. As a participant you will be asked to:

1. Fill out a series of questionnaires
2. Participate in basic attention tasks
3. Drive through a simulated traffic environment
4. Fill out a short exit questionnaire

Procedure

There are four parts to this study. In the first part you will fill out a questionnaire to provide your demographic information, as well as some information on your driving habits. In the second part you will be directed to complete some interactive visual tasks on a computer. In the third part you will drive through experimental scenarios. We ask that you attempt to 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. Before driving, approximately 25 minutes will be used to configure the eye-tracker and introduce you to the simulator; you will be given time to test it and become comfortable driving with it. Next, there will be three driving scenarios of 10 minutes each, with small five minute breaks in between. In the final part, you will fill out a short exit questionnaire.

Risks

There are no major risks involved with this experiment, the tasks are not physiologically demanding, psychologically stressing, and there is no manipulation or deception involved. 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 feel any of these symptoms appear, 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 conducting this study. The most important benefit is your contribution to research in traffic safety, which will guide the development of methods to encourage long term improvements in driver performance. You will also gain experience with academic research and be able to use and test out a state of the art driving simulator.

Compensation

You will receive $15/hr for your participation plus a $5 experiment completion bonus at the end of this study.

Confidentiality

All information obtained during the study will be held in strict confidence. You will be identified with 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 the investigators in this study.

Please be advised that we video-record the experimental trials with four small web-cameras. One camera will be pointed at you, one will capture the steering wheel, one the pedals, and the final camera the overall scene. We will use four other cameras on and near the dashboard to track and record where you are looking during the experiment. The videos will only be seen by the investigators, the primary investigator’s research assistant, and research collaborators. Faces will be blurred in any video used in public presentations.

Participation

Your participation in this study is voluntary. You can choose to not participate or withdraw at any time.

Questions

If you have any general questions about this study, please call 416.978.0881 or email lha@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 F: Experiment 1 experimenter guidelines

Experimenter Guidelines– April 2nd, 2014

Distracted Driving Study

Pre-participant Setup

1. Turn on the simulator (cab, minisim computer, video computer, facelab computer, eyeworks computer, and monitors, make sure that dashboard display button is lit up: this is located near the cab button).
2. Make sure cameras are in the right locations (front camera, rear overhead camera, brake camera).
3. Make sure that the Ethernet cable is plugged into the usb adapter on the Microsoft Surface Pro
4. Make sure the power cable is plugged into the surface (also double check that the power settings on the surface are still set to enough time so that the screen will not shut off in the middle of the experiment ~ 30 minutes)
5. Open Netbeans and Windows Movie Maker on the Surface Pro
6. Make sure that the AnimationTask, MatchingTask_practice, and MatchingTask are in the projects panel
7. Have receipts, consent form, work load/between drive questionnaire ready.

Meeting with the Participant

8. Introduce yourself.
9. Tell the participant where to put their personal belongings (in a designated area outside the experimental room or on top of the filling cabinet in the simulator room).
10. Tell participant to remove their watch and to silence their phones or pagers.
11. Request that they put their watch/electronics devices with their belongings or that you could hold on to it for them.
12. Give the participant the consent form and tell them to read them.
13. Tell the participant that participation is voluntary and that they can choose not to participate.
14. Ask participant how much sleep they have had and how alert they feel today.
15. Offer to answer any questions regarding the consent form.
16. If they desire to participate, have participant sign the consent form.
17. Tell the participant that they are free to withdraw at any time without penalty, but they will only be paid based on the amount of time completed.
18. Make sure that 1B_Toyota_P3.scn, 1B_Toyota_A3.scn, 1B_Toyota_B3.scn, 1B_Toyota_C3.scn, 1B_Toyota_signs.scn files are in the simulator folder: C:\NadsMiniSim_V2.0\Data

19. If the participant number you are running doesn't exist, add it to ExperimentConfig.txt in the C:\NadsMiniSim_V2.0\Data\Rcm_data folder

Participant Simulator Set-up

20. Tell participant that they will be required to undergo the eye calibration test.

> *"Before we begin the experiment, we will need to undergo an eye calibration test to see if we are able to capture information about where you are looking on the simulator"*

21. Ask the participant to take a seat in the simulator.
22. Ask the participant to adjust the seat and steering wheel so that the participant is sitting in a comfortable position (steering wheel adjustment is on left side of steering wheel and seat adjustment is under the seat at the front).
23. Instruct the participant to sit in the chair at relatively stable position throughout the session. Inform them that the driving session will last for approximately 1.5 hours.

> *"Please have a seat in the driver's seat. You may adjust the seat or steering wheel so that you are comfortable."*

Eye Calibration Test

1. In order to determine if the participant is eligible for the experiment, he/she has to go through an eye calibration test to make sure his/her eyes are calibrating as per experiment requirement.

ON FACELAB PC

1) Open FaceLab5, choose Liberty_distraction, change world to Liberty_distraction (surface should be in model)
2) Go to "CONTROLS" Tab, click Stereo-Head Tab
3) Click "RECALIBRATE" follow instructions until finished: Hit switch button to put on centre screen and use the allen key to adjust the eye tracking cameras in 3 degrees of freedom
4) When adjusting focus, or checking tracking accuracy, have the participant look (with head movement) to the different corners of the centre screen.
5) Go to "faceLAB" main tab
6) Click "SET MODEL"
7) Then Click "HeadModel" Drop down and select "Edit Head Model" – go through steps
8) 80-85% is the benchmark for how much the eye tracker picks up when looking straight ahead (source: eyetracking company).
9) Go to "WORLD" Tab
10) Click File, Open – Liberty Distraction Setup

11) In “WORLD” Tab – Click ‘Center Screen’ (right side of tab)
    a. Click “Calibration” Tab
    b. Click “Show SID”
        i. Good dimensions for the square are: Calab position: x = -.45, y = .26; Calab size x = .91, y = .51
    c. Follow calibration
    d. Get participant to look at the different screens, dashboard, and surface. If there is a problem try changing the IR and redo the calibration
        i. Lower IR pod (x = 0, y = -2, z = 12) Upper IR pod(x = 3, y = 46, z = -28)

12) Go to “CONTROLS” Tab, select “LOGGING” panel
    a. Select “Log Realtime” under Network Address select ‘UTMiniSim’ (or type IP address of Minisim 90.0.0.1)
    b. Port should be set to 2020
    c. When using precision eye tracking, must also set eye tracker to log to disk (select directory to save in and base file name)

ON EYEWORKS PC

1) Open EyeWorks Record Software
2) Under CONTROLS
    a. System Type = Seeing Machines – faceLAB
    b. System IP Address: 90.0.0.2
    c. Output file – select directory and output file name to save
3) Under SETTINGS
    a. “click” box for Record Video
    b. Mode = External Video Source: Datapath VisionRGB-E1S Video 01
        i. Click on settings button beside External Video
        ii. Resolution should be 1360x768
        iii. Framerate 60

Experiment Goals and Task Familiarization

1. Open the Netbeans on the surface
2. Make the participant aware that their main goal in this study is the safe operation of the vehicle during the driving scenarios. The participants should drive as they normally would in their actual vehicles. Inform them of the word matching experimental task

> “*Your main task in this study will be the safe operation of the vehicle. Please drive as you would in your own vehicles.*
>
> *You will be completing three drives through a rural and urban driving environment. During one of these drives you will perform a word matching task on the surface. Your task will be to select a phrase out of 10 phrases that matches the phrase*

'Discover Project Missions'. A phrase qualifies as a match if it has either 'discover' first, "Project" second, or "Missions" third. For example "Discover Missions Project" is a match because it has "Discover" first, whereas "Project Discover Misguide" is not a match because none of the target words are in the correct place. There is only one correct answer in the list of 10 candidate phrases and you can use the up and down arrows to scroll through the options. Press submit when you have selected the answer. You can choose when to perform the task once it is available, but please try to drive as you normally would."

3. Have participants try the task on the surface. The correct file is MatchingTask_practice
4. Let the participants run the practice tasks again if they feel they need more practice (or if they are not able to perform the last 3 tasks perfectly)
5. Answer any questions or concern that he/she might have.

Notes about Simulator sickness

- Driving while holding head static and eyes fixed to the front can be an indicator of simulator sickness
- Inform participant that it takes time to adapt, that some people do not feel their best in the simulator and that you want to know if the participant feels any symptoms.
- Simulator sickness does not get better if you try to 'tough it out'
- Encourage slow stops in practice drive

At first sights of simulator sickness

1. Pause the drive / put in park
2. Shut eyes
3. Put a foot on the floor
4. Perform slow head turning (while seated) first with eyes shut, then open
5. Have water, mess basin, towelettes available
6. Rest 5 minutes, brief walk, accompany subject
7. Reinitiate or discontinue experiment

Post experiment

- Tell participants to test brakes before they drive their actual car after experiment

Practice Scenario

1. After the familiarization, proceed to practice scenario. Close the Pebble Relay software before continuing.

"We will now go through a practice scenario to become familiarized with the driving simulator."

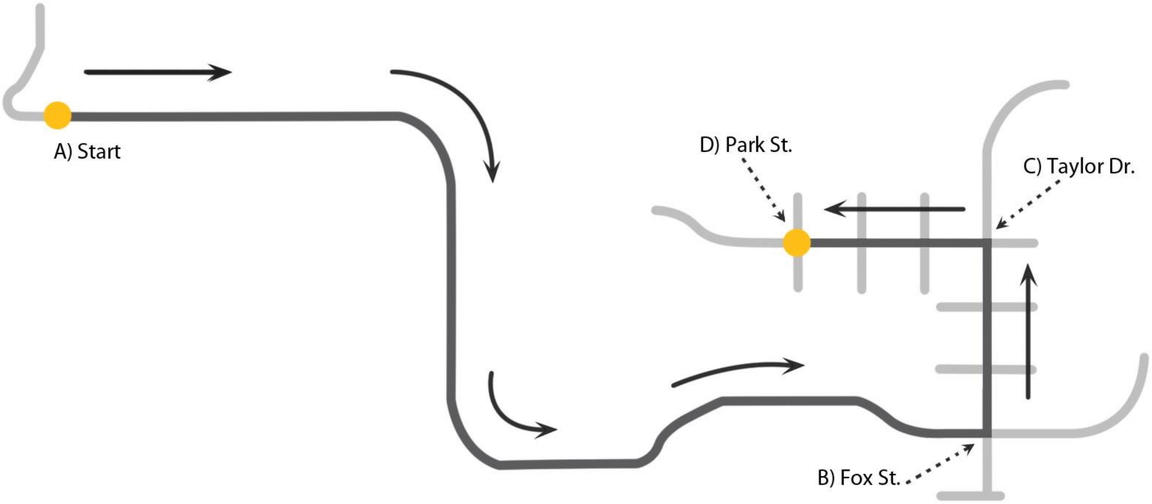
2. Turn on the minisim program. Make sure the experiment is set to Pebble and select the correct participant ID.
3. Import the liberty toyata signs scenario.
4. Import the 1B_Toyota_P3 scenario and start the drive.
5. Turn off the lights.
6. Tell the participant that they should get accustomed to the feel and control of the simulator during this portion. Have them accelerate and break, and then drive till they get around the first curve. Let the participant know that if they feel sick or nauseous at any time that they should stop the experiment and drive.

   “*Know you will have a chance to become accustomed the feel and control of the simulator. When you're ready, accelerate for a bit, and then come to a complete stop. If you feel comfortable with that, continue driving until you come around the first curve. If you feel sick or nauseous at any time, please let me know and we will stop the experiment.* ”

7. Once the participant finishes the previous portion, have them stop and put the car in park. Then stop the simulator.
8. Load the practice drive task on netbeans: MatchingTask_practiceDrive

   “*During the next practice scenario you will drive through a rural and urban environment and get a sense for what the task feels like while driving.”*

9. Give the participant the instructions for the practice session. Show them the map and continue with the following instructions:



1) During the experiment please drive in the left-most lane when possible.

2) Start driving after the experimenter has indicated you may do so and when you feel comfortable, the car in front of you will start after you start driving. Follow the car in front of you and do not pass. Unless the car in front of you is braking with the brake lights on, try maintain the speed limit of 50 mph.
3) At some point the car in front of you will speed away, you no longer need to follow him. I will let you know when you do not have to follow him any longer.
4) Turn left at Fox St. (the first intersection you reach). Wait for the first car to enter the intersection before choosing an appropriate gap in which to make your turn.
5) After you turn the speed limit is now 35 mph.
6) Continue straight until Taylor Dr. Once again, wait for the first car to enter the intersection before choosing an appropriate gap in which to make your turn.
7) Continue straight. When you reach the red lights at Park St. put the car into park to finish the drive.

"Here is a map of the route that you will be driving (above). I will remind you of these points during the practice drive.When you're ready to begin, please follow the car ahead."

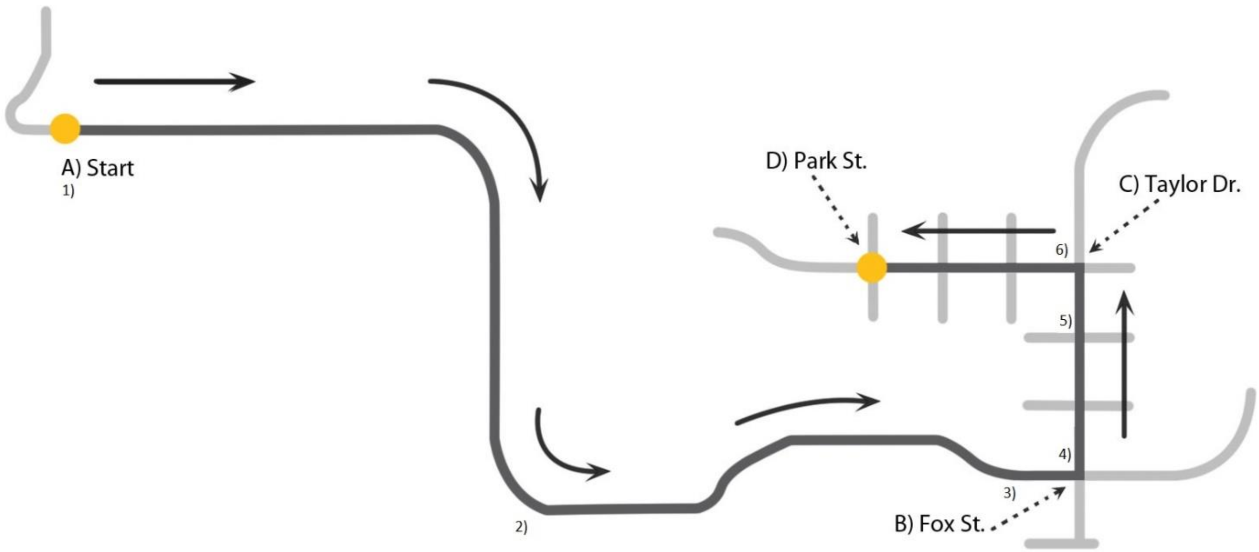
10. Answer any questions that the participants have and remind them of the events as they occur.
11. Have the participant put the car in park at the end of the practice session and then stop the drive using the simulator computer.

"How are you feeling? Do you need a break?"

Experimental Trials

Be upfront about not talking during the experiment.

12. Load the appropriate experiment scenario for the 1st, 2nd, or 3rd drive on the simulator computer (1B_Toyota_A3.scn, 1B_Toyota_B3.scn, 1B_Toyota_C3.scn).
13. Always ask if the participant needs a break in between drives to walk around and get water etc.
14. Directions:
    1) Start when you are comfortable, the speed limit is 50mph
    2) You no longer need to follow the car in front of you
    3) Turn left at the next intersection
    4) Continue straight, the speed limit is now 35mph
    5) Turn left at the next intersection
    6) Continue straight and stop when you reach the red lights



15. If the condition is **involuntary**:
    a. Check the Ethernet is still plugged into the display
    b. Start Windows Movie Maker, click ‘Webcam video”, click “record” & then make sure to stop and save after the drive
    c. Make sure all other netbeans projects are stopped
    d. Start AnimationTask project in netbeans

“For this drive there will be a sound and an animation that appears on the display periodically. You do not need to interact with it.”

16. If the condition is **voluntary**:
    a. Check the Ethernet is still plugged into the display
    b. Start Windows Movie Maker, click ‘Webcam video”, click “record” & then make sure to stop and save after the drive
    c. Make sure all other netbeans projects are stopped
    d. Start MatchingTask project in netbeans

For this drive you will be performing a matching task.

> *You will be completing three drives through a rural and urban driving environment. During one of these drives you will perform a word matching task on the surface. Your task will be to select a phrase out of 10 phrases that matches the phrase ‘Discover Project Missions’. A phrase qualifies as a match if it has either ‘discover’ first, “Project” second, or “Missions” third. There is only one correct answer in the list of 10 candidate phrases and you can use the up and down arrows to scroll through the options. Press submit when you have selected the answer.”*
>
> *Do you feel that you understand the task?*

If no, perform the practice task again until they do.

> *"During the drive this task will be available at all times. You can choose when to perform the task. Perform the task only when you feel comfortable doing so and at a pace that you are comfortable with. This is not an experiment in risk taking; your primary task, as in the real world, is to drive safely at all times so please prioritize driving as you normally would."*

17. If the condition is **baseline**:
18. Open moviemaker and start recording webcam video
19. Go to control panel -> appearance and personalization -> personalization -> change screen saver -> set screen saver to 'blank' & click preview button with your finger (not the pen)

20. After the drive, have the participants fill out the post-drive questionnaire on paper. Enter the participant ID, drive #, and condition before giving the survey to the participant. Let the participant know that they can take a break afterwards if they want before continuing with the drives.

    > "*Please fill out this questionnaire which will help us understand how you found the notifications and the drive. Afterwards, you can take a short break before continuing with the rest of the drives."*

21. Repeat for the rest of the drives.

Post Experiment

22. Once they finish all the drives, thank them for their time and ask if they have any final questions or comments.
23. Fill out a receipt form based on the number of hours taken. ($15/hr + $5 for completion).

Appendix G: Experiment 1 post-drive survey

Participant #________________

Drive #____________________

Drive Condition (circle):

- **Baseline**
- **Animation**
- **Matching**

PERCEIVED RISK (After Each Drive)

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

NASA-TLX Mental Workload Rankings

For each of the pairs listed below, circle the scale title that represents the more important contributor to workload during the driving condition

Mental Demand or Physical Demand

Mental Demand or Temporal Demand

Mental Demand or Performance

Mental Demand or Effort

Mental Demand or Frustration

Physical Demand or Temporal Demand

Physical Demand or Performance

Physical Demand or Effort

Physical Demand or Frustration

Temporal Demand or Performance

Temporal Demand or Frustration

Temporal Demand or Effort

Performance or Frustration

Performance or Effort

Frustration or Effort

Definition of Task Demand Factor

Mental demand

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

Physical demand

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

Temporal demand

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

Performance

How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

Frustration level

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

Effort

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

NASA-TLX Mental Workload Rating Scale

Please place an “X” along each scale at the point that best indicates your experience with the driving condition.

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

Low High

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

Low High

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

Low High

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

Low High

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

Low High

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

Low High

Appendix H: Experiment 1 descriptive statistics for lead vehicle braking metrics

DRIVING METRIC	**INVOLUNTARY DISTRACTION**			**VOLUNTARY DISTRACTION**			**BASELINE**		
	N	*Mean (ms)*	*SD (ms)*	*N*	*Mean (ms)*	*SD (ms)*	*N*	*Mean (ms)*	*SD (ms)*
ART	69	1106	555	49	1163	536	68	940	545
BTT	69	770	471	49	705	531	68	779	479
BRT	69	1875	725	49	1868	742	68	1720	680
PT	42	562	586	38	849	556	51	711	795
IT	68	913	500	43	770	494	61	754	519
		(s)	(s)		(s)	(s)		(s)	(s)
TTC$_{min}$	69	9.0s	3.7s	49	10.7	6.9	68	10.3s	4.7s
		(m/s^2)	(m/s^2)		(m/s^2)	(m/s^2)		(m/s^2)	(m/s^2)
MAX DECELERATION	69	-4.37	1.56	49	-4.28	1.40	68	-4.34	1.34

Appendix I: Experiment 1 detailed lead vehicle braking results

Table I1 Lead vehicle braking event statistical modeling results. Interaction terms in grey were systematically removed from the final models

Response variable	Gap time		Road curvature		Distraction		SRDE	
	F-value	*p*	F-value	*p*	F-value	*p*	F-value	*p*
ART	F(1,146) = 5.89	0.02	F(1, 146) = 1.01	0.32	F(2, 146) = 5.15	0.007	F(2, 33) = 1.08	0.35
BTT	F(1, 146) = 6.06	0.02	F(1,146) = 11.41	0.0009	F(2,146) = 3.02	0.05	F(2,146) = 0.24	0.79
BRT	F(1,146) = 9.93	0.002	F(1, 146) = 11.47	0.0009	F(2, 146) = 1.77	0.17	F(2, 33) = 0.24	0.79
Maximum deceleration	F(1, 144) = 0.84	0.36	F(1, 144) = 0.01	0.91	F(2, 144) = 0.30	0.74	F(2, 33) = 1.41	0.26
TTC_{min}	F(1, 146) = 0.04	0.84	F(1, 146) = 37.18	<.0001	F(2, 146) = 3.55	0.03	F(2, 33) = 0.49	0.62
PT	F(1, 92) = 8.45	0.005	F(1, 92) = 3.28	0.07	F(1, 92) = 2.14	0.12	F(2, 32) = 1.16	0.33
IT	F(1, 132) = 18.27	<.0001	F(1, 132) = 1.96	0.16	F(2, 132) = 8.02	0.0005	F(2, 32) = 0.06	0.95

Distraction * SRDE		Distraction * Gap time		Distraction * Road curvature		SRDE * Gap time		SRDE * Road curvature	
F-value	*p*	F-value	*p*	F-value	*p*	F-value	*p*	F-value	*p*
ART continued… F(4, 139) = 1.03	0.39	F(2, 143) = 0.90	0.41	F(2, 137) = 0.65	0.52	F(2, 135) = 0.40	0.67	F(2, 133) = 0.06	0.94
BTT continued… F(4, 138) = 1.14	0.34	F(2,144) = 1.13	0.32	F(2, 133) = 0.04	0.96	F(2, 142) = 1.00	0.37	F(2, 135) = 0.30	0.74
BRT continued… F(4, 142) = 1.52	0.2	F(2, 137) = 0.75	0.47	F(2, 139) = 0.95	0.39	F(2, 135) = 0.91	0.41	F(2, 133) = 0.43	0.65
Maximum deceleration continued… F(4, 137) = 0.83	0.51	F(2, 144) = 3.34	0.04	F(2, 135) = 0.38	0.68	F(2, 142) = 2.63	0.08	F(2, 133) = 0.13	0.88

TTC$_{min}$ continued… F(4, 133) = 0.27	0.9	F(2, 140) = 0.99	0.38	F(2, 144) = 1.31	0.27	F(2, 137) = 0.37	0.69	F(2, 142) = 1.44	0.28
PT continued… F(4, 86) = 1.80	0.14	F(2, 79) = 0.07	0.94	F(2, 82) = 1.29	0.28	F(2, 90) = 2.82	0.06	F(2, 84) = 1.32	0.27
IT continued… F(4, 120) = 0.98	0.42	F(2, 124) = 0.65	0.53	F(2, 128) = 1.19	0.31	F(2, 126) = 1.00	0.37	F(2, 130) = 1.18	0.31

Road curvature * Gap time		Gap time * Distraction * SRDE		Road curvature * Distraction * SRDE		Road curvature * Gap time * SRDE		Road curvature * Gap time * Distraction		Road curvature * Gap time * Distraction * SRDE	
F-value	*p*	F-value	*p*	F-value	*p*	F-value	*p*	F-value	*p*	F-value	*p*
ART continued… F(1, 145) = 2.34	0.13	F(4, 129) = 1.85	0.12	F(4, 125) = 1.67	0.16	F(2, 123) = 0.90	0.41	F(2 121) = 0.10	0.9	F(4, 117) = 1.01	0.41
BTT continued… F(1, 137) = 0.49	0.48	F(4, 127) = 0.77	0.55	F(4, 121) = 0.46	0.76	F(2, 125) = 0.34	0.71	F(2, 131) = 2.39	0.1	F(4, 117) = 1.26	0.29
BRT continued… F(1, 141) = 1.23	0.27	F(4, 125) = 1.09	0.37	F(4, 121) = 0.95	0.44	F(2, 131) = 1.69	0.19	F(2, 129) = 1.47	0.23	F(4, 117) = 1.01	0.4
Maximum deceleration continued… F(1, 141) = 0.55	0.46	F(4, 125) = 0.80	0.53	F(4,129) = 1.18	0.32	F(2, 121) = 0.009	0.99	F(2,123) = 0.47	0.63	F(4, 117) = 0.43	0.79
TTC$_{min}$ continued… F(1, 139) = 0.39	0.53	F(4, 125) = 1.18	0.32	F(4,129) = 1.83	0.13	F(2,123) = 0.04	0.97	F(2,121) = 0.03	0.97	F(4, 117) = 0.28	0.89
PT continued… F(1, 81) = 0.08	0.78	F(4, 71) = 1.26	0.29	F(4, 67) = 1.35	0.26	F(2, 75) = 1.83	0.17	F(2, 77) = 1.88	0.16	F(4,63) = 0.59	0.67
IT continued… F(1, 132) = 7.35	0.008	F(4, 116) = 1.30	0.27	F(4, 108) = 0.35	0.85	F(2, 114) = 1.49	0.23	F(2, 112) = 0.33	0.72	F(4, 104) = 0.86	0.49

Appendix J: Experiment 1 detailed non-braking-event results

Table J1 Non-braking-event statistical modeling results (samples where participants did not engage with the secondary task under voluntary distraction were excluded). Interaction terms in grey were systematically removed from the final models

Response variable	Distraction type		Region		Region * Distraction type	
	F-value	p	F-value	p	F-value	p
Average speed	F(2, 262) = 6.92	.001	F(2, 262) = 1024.26	< .0001	F(4, 258) = 0.35	.84
SDLP	F(2, 262) = 2.28	.10	F(2, 262) = 93.18	< .0001	F(4, 258) = 0.80	.52
Average absolute deviation from target speed	F(2, 262) = 2.41	.09	F(2, 262) = 4.36	.01	F(4, 258) = 1.63	.17
Speed variability	F(2, 258) = 4.41	.01	F(2, 258) = 20.7	< .0001	F(4, 258) = 3.01	.02

Table J2 Non-braking-event statistical modeling results using only samples from the voluntary distraction condition (with participants who did not interact with the secondary task included in the analysis). Interaction terms in grey were systematically removed from the final models

Response variable	SRDE		Region		Region * SRDE	
	F-value	p	F-value	p	F-value	p
Average speed	F(2, 33) = 0.14	.87	F(2, 70) = 286.13	< .0001	F(4, 66) = 0.98	.42
Speed variability	F(2, 33) = 0.54	.59	F(2, 70) = 38.10	< .0001	F(4, 66) = 1.11	.36
SDLP	F(2, 33) = 0.96	.39	F(2, 70) = 19.79	< .0001	F(4,66) = 2.02	.10
Absolute deviation from target speed	F(2, 33)= 0.61	.55	F(2, 70) = 5.05	.009	F(4, 66) = 0.64	.63

Appendix K: Experiment 2 recruitment materials

Mechanical & Industrial Engineering
UNIVERSITY OF TORONTO

Human Factors & Applied Statistics

Participants Needed

For a high-fidelity driving simulator study on driving behavior

Ages 21 to 35
Native English speakers
Must have normal or corrected vision
Must have a valid G driver’s licence or equivalent for at least 3 years

Location: Rosebrugh Building (RS)
164 College Street
Toronto, ON M5S 3G8

Duration: approximately 2 hours and 30 minutes

Compensation: $35 for entire experiment (potential bonus of an additional $5)

Please fill out our screening survey at https://www.surveymonkey.com/r/H2MB9RT so we can assess your eligibility (QR code below). For more information contact us at driverfeedback.hfast@gmail.com

You are eligible for our driving experiment! Details for next steps (Scheduling email)

Hello _____,

Thanks for taking the time to fill out our driving experiment screening questionnaire. You are eligible to participate in our driving simulator experiment studying driving behaviors under different distraction conditions. You will be asked to drive the simulator in four different trials, and then complete computerized attentional tasks. The entire experiment will take approximately 2.5 hours and you will be compensated $35 for entire experiment (potential bonus of an additional $5).

Please fill out this doodle to indicate your availability: http://doodle.com/c49x4qfwry6drdxw (please remember to put your name on your doodle entry). Once you do this we will send an email to confirm a session for you at Rosebrugh Building at 164 College Street, Toronto.

Thank you,
Liberty Hoekstra-Atwood and Susana Marulanda
HFASt Laboratory
Mechanical and Industrial Engineering
University of Toronto

University of Toronto driving experiment confirmation (Confirmation email)

Hello _______,

We are writing to confirm your driving experiment session on ____, _____, 2015 at ______. The experiment will take place at Rosebrugh Building at 164 College Street, Toronto. Please arrive at the entrance of the building: http://map.utoronto.ca/marker/main-entrance-to-the-rosebrugh-building, and one of our researchers will meet you there. Please reply back to confirm you will attend.

The entrance may be difficult to see from the street: when approaching from College Street it is directly to the left of the Terrence Donnelly Ctr for Cellular & Biomolecular Research entrance. If you get lost, need to reschedule, or have any other questions please let us know by replying to this email.

We advise taking public transport to the area, but parking is available on campus if needed.

Thank you,
Liberty Hoekstra-Atwood and Susana Marulanda
HFASt Laboratory
Mechanical and Industrial Engineering
University of Toronto

Reminder email

Hello ___,

This is to remind you that you are scheduled for an experimental session today on _________, 2015 at ______. If you get lost, need to reschedule, or have any other questions please let us know by replying to this email.

Please try to be well rested for the experiment. If you need to correct your vision, please wear contact lenses to the experiment. Please also avoid wearing mascara or other eye makeup. In addition, please wear the type of clothes and shoes you might usually wear when driving. If possible, please bring your driver's license card so we may verify that you meet our study requirements.

Thank you,
Liberty Hoekstra-Atwood and Susana Marulanda
HFASt Laboratory
Mechanical and Industrial Engineering
University of Toronto

You are invited to participate in an HFASt driving simulator study! (Invitation email)

Hello ____,

You are receiving this email because you indicated interest in hearing about future experiments on a previous HFASt survey. We are recruiting participants for a simulator study on driving behaviours. You will be asked to complete a questionnaire, some computer-based cognitive tasks, and drive the simulator.

The experiment will take approximately 2.5 hours and you will be compensated $35 for entire experiment (potential bonus of an additional $5)
If you are interested in participating in this study, please fill out a brief survey here: https://www.surveymonkey.com/r/H2MB9RT and if you are eligible we will send you further information. If you have any questions about this research, please reply to this email.

Thank you,

Liberty Hoekstra-Atwood and Susana Marulanda
HFASt Laboratory
Mechanical and Industrial Engineering
University of Toronto

Appendix L: Experiment 2 screening survey

You are invited to participate in a driving experiment conducted by the Human Factors and Applied Statistics Lab (Director: Prof. Birsen Donmez) at the Department of Mechanical and Industrial Engineering, University of Toronto. Before you can participate in our driving experiment, you must fill out the below questionnaire so we can determine your eligibility.

The goal of this study is to understand human driving behaviours and make our roads safer. If you choose to participate, you will be presented with questions about yourself and your driving behaviours.

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, separately from the results of the following research survey. Under no circumstances will personal data be revealed to any third party, for any purpose.

If you have any questions or concerns you would like addressed before or after completing this questionnaire, please contact the researchers at driverfeedback.hfast@gmail.com or 416.978.0881.

1. What is your first name?
2. What is your last name?
3. What is your e-mail address?
4. What is your phone number?
5. Choose your preferred method of contact
    a. E-mail
    b. Phone
    c. Either
6. 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).
7. What is your age?
8. What is your sex?
    a. Male
    b. Female
9. Do you currently hold a valid government issued driver’s license?
    a. Yes
    b. No
10. What are your current driver’s licenses
    a. G1
    b. G2
    c. G

    d. Other (please specify)

11. How long ago did you get your full driver's license?

    a. Number of years ____

12. Are you colourblind?

    a. Yes
    b. No
    c. I don't know

13. Do you have normal or corrected-to-normal vision?

    a. Yes
    b. No

14. If you wear glasses for driving, can you wear contact lenses for the experiment?

    a. Yes
    b. No
    c. I do not need glasses

15. Is English your native language?

    a. Yes
    b. No

16. How often do you drive a motor vehicle?

    a. Almost every day
    b. A few times a week
    c. A few times a month
    d. A few times a year
    e. Never

17. Over the last year, how many kilometers have you driven?

    a. Under 10,000 km
    b. Between 10,001 km and 20,000 km
    c. Between 20,001 km and 50,000 km
    d. Over 50,000 km

18. Do you play video games involving driving

    a. No, never
    b. Very rarely
    c. A few times a month
    d. A few times a week

19. What is your dominant hand?

    a. Right
    b. Left
    c. I'm ambidextrous

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.

20. Have you ever driven in a driving simulator?

    a. No, never
    b. Once or twice
    c. Multiple times
    d. Regularly

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

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

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

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

Appendix M: Counterbalanced Experiment 2 orders by SRDE and gender

Gender	Part	Prac1	Prac2	Drive1	Drive2	Drive3	Drive4
M	201	Rural	Urban	Baseline Rural	Distract Rural	Baseline Urban	Distract Urban
F	203	Rural	Urban	Distract Urban	Baseline Rural	Baseline Urban	Distract Rural
M	204	Rural	Urban	Distract Rural	Baseline Urban	Distract Urban	Baseline Rural
F	205	Urban	Rural	Baseline Rural	Baseline Urban	Distract Urban	Distract Rural
F	206	Urban	Rural	Distract Urban	Baseline Urban	Distract Rural	Baseline Rural
F	207	Urban	Rural	Baseline Urban	Distract Urban	Distract Rural	Baseline Rural
F	208	Urban	Rural	Distract Rural	Baseline Rural	Baseline Urban	Distract Urban
F	209	Urban	Rural	Distract Urban	Distract Rural	Baseline Rural	Baseline Urban
M	210	Urban	Rural	Distract Rural	Distract Urban	Baseline Urban	Baseline Rural
F	211	Urban	Rural	Distract Rural	Distract Urban	Baseline Rural	Baseline Urban
M	212	Urban	Rural	Distract Urban	Baseline Rural	Distract Rural	Baseline Urban
M	213	Rural	Urban	Baseline Rural	Baseline Urban	Distract Rural	Distract Urban
M	214	Rural	Urban	Distract Rural	Baseline Urban	Baseline Rural	Distract Urban
M	215	Urban	Rural	Distract Rural	Baseline Rural	Distract Urban	Baseline Urban
M	216	Rural	Urban	Baseline Rural	Distract Rural	Distract Urban	Baseline Urban
M	217	Urban	Rural	Distract Urban	Distract Rural	Baseline Urban	Baseline Rural
M	218	Rural	Urban	Baseline Urban	Distract Rural	Distract Urban	Baseline Rural
F	220	Rural	Urban	Distract Urban	Baseline Urban	Baseline Rural	Distract Rural
F	221	Rural	Urban	Baseline Urban	Distract Urban	Baseline Rural	Distract Rural
F	222	Rural	Urban	Baseline Urban	Distract Rural	Baseline Rural	Distract Urban
F	224	Rural	Urban	Baseline Rural	Distract Urban	Baseline Urban	Distract Rural
M	219	Urban	Rural	Baseline Urban	Baseline Rural	Distract Rural	Distract Urban
M	223	Urban	Rural	Baseline Rural	Distract Urban	Distract Rural	Baseline Urban
F	225	Rural	Urban	Baseline Urban	Baseline Rural	Distract Urban	Distract Rural

Appendix N: Experiment 2 informed consent

Participant Consent Form

Title: Designing feedback to help induce safer driving behaviours

Investigators: Liberty Hoekstra-Atwood (519.807.6848; lha@mie.utoronto.ca)

Susana Marulanda (647.376.3536; smarulan@mie.utoronto.ca)

Winnie Chen (416.978.0881; win.chen@mail.utoronto.ca)

Dr. Birsen Donmez (416.978.7399; donmez@mie.utoronto.ca)

You are being asked to take part in a research study. 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 enough about 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 under the presence of distracting conditions. As a participant you will be asked to:

1. Fill out a series of questionnaires
2. Participate in computer-based cognitive tasks
3. Drive through a simulated traffic environment

Procedure

There are four parts to this study. In the first part you will fill out a questionnaire to provide your demographic information, as well as some information on your driving habits. In the second part you will be directed to complete three interactive cognitive tasks on a computer. In the third part you will drive through experimental scenarios. Before driving, approximately 25 minutes will be used to configure the eye-tracker and introduce you to the simulator; you will be given time to test it and become comfortable driving with it. Next, you will drive through six experimental driving scenarios of approximately 5 minutes each, with small two minute breaks in between. We ask that you attempt to 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. In the final part, you will be directed through the remaining two interactive cognitive tasks on a computer.

Risks

There are no major risks involved with this experiment, the tasks are not physiologically demanding, psychologically stressing, and there is no manipulation or deception involved. 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 feel any of these symptoms appear, 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 conducting this study. The most important benefit is your contribution to research in traffic safety, which will guide the development of methods to encourage long term improvements in driver performance. You will also gain experience with academic research and be able to use and test out a state of the art driving simulator.

Compensation

You will receive $35 for your participation. You can also earn a bonus of up to $5 based on your performance on the cognitive tasks. If you decide to withdraw, you will receive $10 for every hour that you completed.

Confidentiality

All information obtained during the study will be held in strict confidence. You will be identified with 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 the investigators in this study.

Please be advised that we video-record the experimental trials with four small web-cameras. One camera will be pointed at you, one will capture the steering wheel, one the pedals, and the final camera the overall scene. We will use four other cameras on and near the dashboard to track and record where you are looking during the experiment. The videos will only be seen by the investigators, the primary investigator's research assistant, and research collaborators. Faces will be blurred in any video used in public presentations. All digital data will also be stored on a UofT networked-attached storage which can only be accessed through the UofT network and has password protected access.

Participation

Your participation in this study is voluntary. You can choose to not participate or withdraw at any time.

Questions

If you have any general questions about this study, please call 416.978.0881 or email lha@mie.utoronto.ca or smarulan@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 O: Experiment 2 experimenter guidelines

Experimenter Guidelines– January 21st, 2015

Distracted Driving Study

Pre-participant Setup

1. Turn on the simulator (cab, minisim computer, video computer, facelab computer, eyeworks computer, and monitors, make sure that dashboard display button is lit up: this is located near the cab button).
2. Make sure cameras are in the correct locations (front camera, rear overhead camera, brake camera).
3. Make sure that the Ethernet cable is plugged into the usb adapter on the Microsoft Surface Pro
4. Make sure the power cable is plugged into the surface (also double check that the power settings on the surface are still set to enough time so that the screen will not shut off in the middle of the experiment ~ 30 minutes)
5. Open Netbeans and Windows Movie Maker on the Surface Pro
6. Make sure that the AnimationTask, MatchingTask_practice, and MatchingTask are in the projects panel
7. Have receipts, consent form, work load/between drive questionnaire ready.
8. Make sure correct route table is up, eyetracker to minisim is uncommented (minisim.nocab.daq.sf), peripherals are plugged into eyetracker, eyetracking is set to log to minisim

Meeting with the Participant

9. *Introduce yourself.*
10. *Tell the participant where to put their personal belongings (in a designated area outside the experimental room or on top of the filling cabinet in the simulator room).*
11. *Tell participant to remove their watch and to silence their phones or pagers.*
12. *Request that they put their watch/electronics devices with their belongings or that you could hold on to it for them.*
13. Give the participant the consent form and tell them to read them.
14. *Tell the participant that participation is voluntary and that they can choose not to participate.*
15. *Ask participant how much sleep they have had and how alert they feel today.*
16. Offer to answer any questions regarding the consent form.
17. If they desire to participate, have participant sign the consent form.
18. *Tell the participant that they are free to withdraw at any time without penalty, but they will only be paid based on the amount of time completed.*

24. Make sure that Toyota1B_UrbanStart.scn, Toyota1B_RuralStart.scn, and Toyota1B_RuralStart_Acclim.scn files are in the simulator folder: C:\ProgramFiles(x86)\Nads\Isat\data
19. If the participant number you are running doesn't exist, add it to ExperimentConfig.txt in the C:\NadsMiniSim_V2.2\Data\Rcm_data folder

Participant Simulator Set-up

20. Tell participant that they will be required to undergo the eye calibration test.

> *"Before we begin the experiment, we will need to undergo an eye calibration test to see if we are able to capture information about where you are looking on the simulator"*

21. Ask the participant to take a seat in the simulator.
22. Ask the participant to adjust the seat and steering wheel so that the participant is sitting in a comfortable position (steering wheel adjustment is on left side of steering wheel and seat adjustment is under the seat at the front).
23. Instruct the participant to sit in the chair at relatively stable position throughout the session.

> *"Please have a seat in the driver's seat. You may adjust the seat or steering wheel so that you are comfortable."*

Eye Calibration Test

1. In order to determine if the participant is eligible for the experiment, he/she has to go through an eye calibration test to make sure his/her eyes are calibrating as per experiment requirement.

ON FACELAB PC

1) Open FaceLab5, choose Liberty_distraction, change world to Liberty_distraction (surface should be in model)
2) Go to "CONTROLS" Tab, click Stereo-Head Tab
3) Click "RECALIBRATE" follow instructions until finished: Hit switch button to put on centre screen and use the allen key to adjust the eye tracking cameras in 3 degrees of freedom
4) When adjusting focus, or checking tracking accuracy, have the participant look (with head movement) to the different corners of the centre screen.
5) Go to "faceLAB" main tab
6) Click "SET MODEL"

7) Then Click “HeadModel” Drop down and select “Edit Head Model” – go through steps
8) 80-85% is the benchmark for how much the eye tracker picks up when looking ahead from the eyetracking guys.
9) Go to “WORLD” Tab
10) Click File, Open – Liberty Distraction Setup
11) In “WORLD” Tab – Click ‘Center Screen’ (right side of tab)
    a. Click “Calibration” Tab
    b. Click “Show SID”
        i. Good dimensions for the square are: Calab position: x = -.45, y = .26; Calab size x = .91, y = .51
    c. Follow calibration
    d. Get participant to look at the different screens, dashboard, and surface. If there is a problem try changing the IR and redo the calibration
        i. Lower IR pod (x = 0, y = -2, z = 12) Upper IR pod(x = 3, y = 46, z = -28)
12) Go to “CONTROLS” Tab, select “LOGGING” panel
    a. Select “Log Realtime” under Network Address select ‘UTMiniSim’ (or type IP address of Minisim 90.0.0.1)
    b. Port should be set to 2020
    c. When using precision eye tracking, must also set eye tracker to log to disk (select directory to save in and base file name)

ON EYEWORKS PC

1) Open EyeWorks Record Software
2) Under CONTROLS
    a. System Type = Seeing Machines – faceLAB
    b. System IP Address: 90.0.0.2
    c. Output file – select directory and output file name to save
3) Under SETTINGS
    a. “click” box for Record Video
    b. Mode = External Video Source: Datapath VisionRGB-E1S Video 01
        i. Click on settings button beside External Video
        ii. Resolution should be 1360x768 (Main screen on minisim should be 4080x768)
        iii. Framerate 60
4) If a grey screen with red dot appears, go to options -> advanced -> seeing machines tab -> and uncheck calibrate gaze

Experiment Goals

1. Inform them that the driving session will last for approximately 30 -40 minutes.

"The driving part of the experiment should take around 30-40 minutes. You will do an acclimatization drive to get used to the dynamics of the simulator and two practice drives. You will then perform 4 experimental drives. I will ask you if you want to take breaks or have water in between"

Notes about Simulator sickness

"Simulator sickness is common for people using the simulator. Simulator sickness does not get better if you try to 'tough it out'. So, if you experience any symptoms of nausea or dizziness please let me know and we can take a break for water and to walk around and then decide whether or not to continue the experiment. There are also bags available on the side of the cab if required."

- Driving while holding head static and eyes fixed to the front can be an indicator of simulator sickness
- Inform participant that it takes time to adapt, that some people do not feel their best in the simulator and that you want to know if the participant feels any symptoms.
- Simulator sickness does not get better if you try to 'tough it out'
- Encourage slow stops in practice drive

At first sights of simulator sickness

1. Pause the drive / put in park
2. Shut eyes
3. Put a foot on the floor
4. Perform slow head turning (while seated) first with eyes shut, then open
5. Have water, mess basin, towelettes available
6. Rest 5 minutes, brief walk, accompany subject
7. Reinitiate or discontinue experiment

Post experiment

- Tell participants to test brakes before they drive their actual car after experiment

Familiarization and Practice Scenario

1. Turn on Minisim 2.2 program
2. Load up acclimatization drive: Toyota1B_RuralStart_Acclim.scn
3. Turn off the lights.

4. Tell the participant that they should get accustomed to the feel and control of the simulator during this portion. Have them accelerate and maintain 35mph, then accelerate and maintain 50mph until comfortable. Then have participants practice braking lightly, normally, and a harder brake. Let the participant know that if they feel sick or nauseous at any time that they should stop the experiment and drive.

> "*Now you will have a chance to become accustomed the feel and control of the simulator. When you're ready start the car; the lead vehicle will start driving after you start driving. Accelerate to 35mph and try to maintain that speed until you feel comfortable doing so. If you feel sick or nauseous at any time, please let me know and we will stop the experiment. Now increase your speed to 50mph and maintain that speed until you feel comfortable doing so. Now please brake lightly and accelerate, then brake normally and accelerate. Now please try a hard brake. Do you feel comfortable? Would you like more practice?*"

Practice drive

> "*We will now drive through two practice drives. If you have any questions let me know, I will not be speaking during the actual experimental drives.*"

> "*Driving is your primary task. This is not an experiment in risk taking; your main task, as in the real world, is the safe operation of the vehicle. Please drive as you normally would in your actual vehicle.*"

If too slow (less than 5mph below the speed limit) or very far behind lead vehicle:

> *"Follow the lead car at a close but safe distance, as if following it to a destination"*

Rural

1. Load rural drive

> *"Start driving after the experimenter has indicated you may do so and when you feel comfortable, the car in front of you will start after you start driving. Please follow the car in front of you and do not pass. The car in front of you may adjust its behavior to yours or may also brake periodically. Unless the car in front of you is braking, try maintain the speed limit of 50 mph."*

2. During this drive, if participants go around 45mph or slower, tell them to speed up and try to maintain 50mph
3. Stop drive
4. Answer any questions that the participants have

Urban

5. Load urban drive

> *"Start driving after the experimenter has indicated you may do so and when you feel comfortable, the car in front of you will start after you start driving. Please follow the car in front of you and do not pass. The car in front of you may adjust its behavior to yours or may also brake periodically. Unless the car in front of you is braking, try maintain the speed limit of 35 mph."*
>
> *During the experiment please follow the lead car by driving in the left-most lane when possible."*

6. During this drive, if participants go around 30mph or slower, tell them to speed up and try to maintain 35mph
7. Stop drive
8. Answer any questions that the participants have

Experimental Trials

9. Load the appropriate experiment scenario for the 1st, 2nd, 3rd, or 4th drive on the simulator computer (Toyota1B_UrbanStart.scn and Toyota1B_RuralStart.scn).
10. Always ask if the participant needs a break in between drives to walk around and get water etc.
11. Ask participant about their alertness between each drive (note on question paper)
12. Directions:
13. If the condition is **involuntary**:
    a. Ask if the participant has any questions before starting
    b. Check the Ethernet is still plugged into the display
    c. Open the Netbeans on the surface
    d. Check that the surface sound is at maximum and is working
    e. Start Windows Movie Maker, click 'Webcam video", click "record" & then make sure to stop and save after the drive
    f. Make sure all other netbeans projects are stopped
    g. Start AnimationTask project in netbeans
    h. Turn light on and off and on and off

> *"For this drive there will be a sound and an animation that appears on the display periodically. You do not need to interact with it. Driving is your primary task. This is not an experiment in risk taking; your main task, as in the real world, is the safe operation of the vehicle. Please drive as you normally would in your actual vehicle."*

14. If the condition is **baseline**:
    a. Open moviemaker and start recording webcam video
    b. Go to control panel -> appearance and personalization -> personalization -> change screen saver -> set screen saver to 'blank' & click preview button with your finger (not the pen)
    c. Turn light on and off and on and off

> "*Driving is your primary task. This is not an experiment in risk taking; your main task, as in the real world, is the safe operation of the vehicle. Please drive as you normally would in your actual vehicle."*

15. If the road is **urban**:

> *"Start driving after the experimenter has indicated you may do so and when you feel comfortable, the car in front of you will start after you start driving. Please follow the car in front of you and do not pass. The car in front of you may adjust its behavior to yours or may also brake periodically. Unless the car in front of you is braking, try maintain the speed limit of 35 mph.*
>
> *During the experiment please follow the lead car by driving in the left-most lane when possible.*
>
> *Please let me know if you have any questions now as I will not be speaking during the experiment."*

16. If the road is **rural**:

> *"Start driving after the experimenter has indicated you may do so and when you feel comfortable, the car in front of you will start after you start driving. Please follow the car in front of you and do not pass. The car in front of you may adjust its behavior to yours or may also brake periodically. Unless the car in front of you is braking, try maintain the speed limit of 50 mph.*

> *Please let me know if you have any questions now as I will not be speaking during the experiment.”*

17. Load drive in minisim. Ask participant to look in the middle of the speed limit sign to get an idea of the eyetracking offset.
18. After the drive let the participant know that they can take a break afterwards if they want before continuing with the drives.
19. Ask participant questions for relevant drive
20. Repeat for the rest of the drives.

Post Experiment

21. Ask the two post drive questions on question sheet
22. Once they finish all the drives, thank them for their time and ask if they have any final questions or comments.
23. Fill out a receipt form based on the number of hours taken. ($35/hr + $5 for bonus).

Appendix P: Experiment 2 post-drive questions

Participant: ______________________________

Date: ___________________________________

Prior to drives:

Distraction Urban:

How awake do you feel?

Very sleepy Sleepy Alert Very Alert

Distraction Rural:

How awake do you feel?

Very sleepy Sleepy Alert Very Alert

Baseline Urban

How awake do you feel?

Very sleepy Sleepy Alert Very Alert

Baseline Rural

How awake do you feel?

Very sleepy Sleepy Alert Very Alert

End of all experiment drives

1. How distracting did you find the sound and animation that played on the display in the Urban Environment

   Very distracting Distracting A little distracting Not distracting

2. How distracting did you find the sound and animation that played on the display in the Rural Environment

   Very distracting Distracting A little distracting Not distracting

Appendix Q: Everyday distractibility questions from the Cognitive Failures Questionnaire

Answer the following questions:					
Responses	*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'?					

Appendix R: Revised SDDQ involuntary distraction questions

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

Table R1: Involuntary 1 (difficulty ignoring distractions)

While driving, to what extent would you have difficulty ignoring					
Responses	*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					

Table R2: Involuntary 2 (looking away for longer than intended)

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

Appendix S: Glance metric comparisons between rural and urban environments

- Paired t-tests were performed to compare the aggregated engagement metrics between the rural and urban regions. There were no significant differences (at $p < .05$) for…
    - number of glances ($p = .32$)
    - total glance duration ($p = 47$)
    - average glance duration ($p =.86$)
    - average time to glance initiation ($p = .88$)
- A Wilcoxon test was performed to compare participants' self-reported distractibility rating of the involuntary distraction between the rural and urban environments
    - No significant difference between rural and urban involuntary distraction distractibility rating (W = 87, $p = .36$)
- Further analysis was conducted at the stimulus level (i.e., with repeated measures for the high glance group) using linear mixed-effect models with logarithmic transforms to correct for modelling assumptions.
    - There were no significant relationships found between glance metrics and environmental condition (Table S1).

Table S1 Comparing distraction engagement metrics between environmental conditions using linear mixed models

	Environment	
Response variable	F-value	*p*
Total duration of glances per distraction (Pearson)	F(1, 60) = 0.50	.48
Average duration of glances per distraction (Pearson)	F(1, 60) = 0.04	.85
Glance initiation time (Pearson)	F(1, 60) = 0.05	.82

Appendix T: Glance metric comparisons to revised SDDQ involuntary subscales

- Linear regression models were used to compare the mean responses of participants to the involuntary distraction sections of the revised SDDQ between participants in the high glance group and the low glance group. Scores of interest were…
    - The mean Involuntary 1 score (Difficulty ignoring distractions) (N = 23, $\bar{x}$ = 2.7, SD = 0.6)
    - The mean Involuntary 2 score (Looking away for longer than intended) (N = 23, $\bar{x}$ = 2.2, SD = 0.6)
    - The average of all the Involuntary 1 and 2 scores (N = 23, $\bar{x}$ = 2.5, SD = 0.5)
- There were no significant differences between the mean individual Involuntary section scores for each glance group (Participant 201 was removed for this analysis: see section 3.6.2.2) (Table T1)
- There was a marginally significant relationship between the average of all Involuntary 1 and 2 scores and glance group (Table T1). Participants who glanced more than once had a greater average score (+ 0.37) compared to those who glanced once or not at all. (Participant 201 was removed for this analysis: see section 3.6.2.2)

Table T1 Comparison of the revised SDDQ involuntary scores between high and low glance groups

	Glance group	
Response variable	F-value	*p*
All involuntary questions mean	F(1, 21) = 4.83	.08
Involuntary 1 mean	F(1, 21) = 2.34	.14
Involuntary 2 mean	Wilcoxon (W = 43)	.16

- Correlations were performed between glance metrics for participants who glanced at least once at the stimuli and their responses to the revised SDDQ involuntary questions (Table T2).

Table T2 Correlations between the revised SDDQ Involuntary questions and glance metrics for participants who glanced

	All involuntary questions mean		Involuntary 1 mean		Involuntary 2 mean	
	Correlation coefficient	*p*	Correlation coefficient	*P*	Correlation coefficient	*p*
Number of glances (Spearman)	r(13) = .19	.49	r(13) = -.02	.95	r(13) =.17	.55
Total duration of glances (Pearson)	r(13) = .05	.87	r(13) = -.02	.95	r(13) =.14	.63
Average duration of glances (Pearson)	r(13) = .11	.68	r(13) = .12	.68	r(13) =.07	.80
Average glance initiation time (Pearson)	r(13) = -.11	.71	r(13) = .11	.70	r(13) = -.08	.79

- Further analysis was conducted at the stimulus level (i.e., with repeated measures for the high glance group) using linear mixed-effect models with logarithmic transforms to correct for modelling assumptions.
- There were no significant relationships found between the mean responses to the revised SDDQ involuntary question sections and glance metrics at the stimulus level (Table T3, Table T4, and Table T5).

Table T3 Relationships between the mean of the revised SDDQ Involuntary 1 and 2 scores and involuntary distraction engagement metrics per distraction using mixed linear models

	Involuntary 1 and 2 mean	
Response variable	F-value	*P*
Total duration of glances per distraction (Pearson)	F(1, 13) = 0.26	.53
Average duration of glances per distraction (Pearson)	F(1, 13) = 0.02	.90
Glance initiation time (Pearson)	F(1, 13) = 0.42	.53

Table T4 Relationships between the revised SDDQ Involuntary 1 score and involuntary distraction engagement metrics per distraction using mixed linear models

	Involuntary 1 mean	
Response variable	F-value	*p*
Total duration of glances per distraction (Pearson)	F(1, 13) = 0.39	.39
Average duration of glances per distraction (Pearson)	F(1, 13) = 0.11	.74
Glance initiation time (Pearson)	F(1, 13) = 2.13	.16

Table T5 Relationships between the revised SDDQ Involuntary 2 score and involuntary distraction engagement metrics per distraction using mixed linear models

	Involuntary 2 mean	
Response variable	F-value	*p*
Total duration of glances per distraction (Pearson)	F(1, 13) = 0.004	.95
Average duration of glances per distraction (Pearson)	F(1, 13) = 0.02	.89
Glance initiation time (Pearson)	F(1, 13) = 0.07	.79

Appendix U: Glance metric comparisons to Stroop task RI

- Analysis of participants' Stroop task relative interference (RI), where greater negative interference indicates poorer distraction suppression ability (N = 24, $\bar{x}$ = -21.1, SD = 12.7)
- A linear regression model was used to compare participants' RI between the low glance group and the high glance group; there was no significant difference between glance group RIs (F(1,22) = 1.28, *p* = .27)
- Correlations were performed between glance metrics for participants who glanced at least once at the stimuli and their RI; there were no significant relationships (Table U1).

Table U1 Correlations between glance metrics for participants who glanced toward the stimuli and their relative interference in the Stroop task

	Relative interference: Stroop task	
	Correlation coefficient	*p*
Number of glances (Spearman)	r(14) = -.17	.52
Total duration of glances (Pearson)	r(14) = -.10	.70
Average duration of glances (Pearson)	r(14) = -20	.45
Average glance initiation time (Pearson)	r(14) =.24	.36

- Further analysis was conducted at the stimulus level (i.e., with repeated measures for the high glance group) using linear mixed-effect models with logarithmic transforms to meet modelling assumptions; there were no significant relationships found (Table U2)

Table U2 Relationships between the Stroop task relative interference and involuntary distraction engagement metrics per distraction using mixed linear models

	Relative interference: Stroop task	
Response variable	F-value	*p*
Total duration of glances per distraction	F(1, 14) = 0.10	.76
Average duration of glances per distraction	F(1, 14) = 0.26	.62
glance initiation time	F(1, 14) = 0.12	.73

Appendix V: Glance metrics versus flanker compatibility effects

- Analysis of relative flanker effect (R_{FCE}) from all participants (N = 24, $\bar{x}$ = -7.8, SD = 5.4), where a larger negative relative flanker effect indicates poorer distraction suppression ability
- Linear regression model used to relate R_{FCE} in the low perceptual load condition to participants' high and low glance group; no significant difference (F(1,22) = 0.10, *p* = .76)
- Correlations were performed between glance metrics for participants who glanced at least once at the stimuli and their R_{FCE}; no significant relationships (Table V1).

Table V1 Correlations between glance metrics for participants who glanced toward the stimuli and their relative flanker effect

	Relative flanker compatibility effect	
	Correlation coefficient	*p*
Number of glances (Spearman)	r(14) = -.10	.71
Total duration of glances (Pearson)	r(14) = .10	.72
Average duration of glances (Pearson)	r(14) = .39	.13
Average glance initiation time (Pearson)	r(14) = -.40	.12

- Further analysis was conducted at the stimulus level (i.e., with repeated measures for the high glance group) using linear mixed-effect models with logarithmic transforms to correct for modelling assumptions; no significant relationships found (Table V2).

Table V2 Relationships between the flanker task relative flanker effect and involuntary distraction engagement metrics per distraction using mixed linear models

	Relative flanker compatibility effect	
Response variable	F-value	*p*
Total duration of glances per distraction	F(1, 14) = 1.40	.25
Average duration of glances per distraction	F(1, 14) = 2.12	.17
glance initiation time	F(1, 14) = 2.07	.17

Appendix W: Glance metrics compared to post-experiment urban and rural distractor ratings

- A Wilcoxon test was performed to examine if there was a difference urban distractor rating for the stimuli in the urban environment between high and low glance groups.
    - The minimum rating was 1 and the maximum was 4 (N = 24, $\bar{x}$ = 1.9, SD = 0.6).
    - There was no significant difference between glance groups' ratings of the experimental stimuli in the urban region (W = 77.5, *p* = .71).
    - Correlations were performed between glance metrics for participants who glanced at least once at the stimuli in the urban environment and their urban distractor rating; no significant relationships (Table W1)

Table W1 Correlations between urban glance metrics for participants who glanced toward the stimuli and their urban distractor rating

	Urban distractor rating	
	Correlation coefficient	*p*
Number of glances (Spearman)	r(13) = .19	.50
Total duration of glances (Spearman)	r(13) = .16	.57
Average duration of glances (Spearman)	r(13) = .04	.88
Average glance initiation time (Spearman)	r(13) = -.29	.29

- Further analysis was conducted at the stimulus level (i.e., with repeated measures for the high glance group) using linear mixed-effect models with logarithmic transforms to correct for modelling assumptions.
- There was a near-significant relationship between glance initiation time and urban distractor rating for the stimuli in the urban environment (Δ=.56, 95% CI: .29, 1.08, *p* = .08) where participants who rated the urban environment stimuli to be more distracting had .56 times faster glance initiation times to the stimuli in the urban environment; no other significant relationships were found (Table W2**Error! Reference source not found.**).

Table W2 Relationships between the urban distractor rating and involuntary distraction engagement metrics per distraction using mixed linear models

	Urban distractor rating	
Response variable	F-value	*p*
Total duration of glances per distraction	F(1, 13) = 0.00	1.0
Average duration of glances per distraction	F(1, 13) = 0.12	.73
glance initiation time	F(1, 13) = 3.64	.08

- A Wilcoxon test was performed to determine if there was a difference in rural distractor rating between high and low glance groups.
    - The minimum rating was 1 and the maximum was 4 (N = 24, $\bar{x}$ = 2.0, SD = 0.7).
    - There was no significant difference in distractor rating in the rural region between glance groups (W = 57, *p* = .37).
- Correlations were performed between glance metrics for participants who glanced at least once at the stimuli in the rural environment and their rural distractor rating; no significant relationships (Table W3).

Table W3 Correlations between rural glance metrics for participants who glanced toward the stimuli and their rural distractor rating

	Rural distractor rating	
	Correlation coefficient	*p*
Number of glances (Spearman)	r(11) =.06	.85
Total duration of glances (Spearman)	r(11) =.10	.74
Average duration of glances (Spearman)	r(11) =-.07	.81
Average glance initiation time (Spearman)	r(11) =-.17	.58

- Further analysis was conducted at the stimulus level (i.e., with repeated measures for the high glance group) using linear mixed-effect models with logarithmic transforms to correct for modelling assumptions; no significant relationships found between rural distractor rating and glance metrics at the stimulus level (Table W4).

Table W4 Relationships between the rural distractor rating and involuntary distraction engagement metrics per distraction using mixed linear models

	Rural distractor rating	
Response variable	F-value	*p*
Total duration of glances per distraction (Pearson)	F(1, 11) = 0.14	.72
Average duration of glances per distraction (Pearson)	F(1, 11) = 0.002	.96
glance initiation time (Pearson)	F(1, 11) = 0.42	.53

Appendix X: Analysis using the difference between rural and urban distractor ratings

- Correlations were performed on the difference between rural and urban distractor ratings and the difference between distraction engagement metrics in the rural and urban environments for all participants
    - Moderate correlation between relative glance numbers (r(22) = .44, *p* = .16) and relative self-reported distraction
    - Moderate correlation between relative total glance duration and distractor rating differences (r(22) = .34, *p* = .10)
    - No significant relationships were observed between the relative distractor rating and the other relative glance metrics (Table X1).

Table X1 Correlations between the glance metric differences and distractor rating differences in the rural vs. urban environments for all participants

	Distractor rating differences: difference between rural and urban environments	
	Correlation coefficient	*p*
Number of glances (Spearman): difference between rural and urban environments	r(22) = .34	.10
Total duration of glances (Spearman): difference between rural and urban environments	r(22) = .44	.16
Average duration of glances (Spearman): difference between rural and urban environments	r(22) = .24	.44
Average glance initiation time (Spearman): difference between rural and urban environments	r(22) = -.18	.57

- Correlations were performed using samples where participants glanced in both the rural and urban environments (N = 12).
    - There was a moderate correlation between relative glance numbers (r(10) = .44, *p* = .16) and relative distractor rating.
    - No significant relationships were observed between the relative distractor rating and the other relative glance metrics (Table X2).

Table X2 Correlations between the glance metric differences and distractor rating differences in the rural vs. urban environments for participants who glanced toward the irrelevant stimuli

	Distractor rating differences: difference between rural and urban environments	
	Correlation coefficient	*p*
Number of glances (Spearman): difference between rural and urban environments	r(10) = .32	.31
Total duration of glances (Spearman): difference between rural and urban environments	r(10) = .44	.16
Average duration of glances (Spearman): difference between rural and urban environments	r(10) = .24	.44
Average glance initiation time (Spearman): difference between rural and urban environments	r(10) = -.18	.57

- The relative difference between high and low perceptual load flanker task conditions (RHL_{FCE}) was correlated with
    - the difference between the distraction engagement metrics (rural-urban)
    - the distractor rating difference (rural-urban)
- There was a marginally significant correlation between RHL_{FCE} and participants' distractor rating difference (r(22) = .36, *p* = .08)
- No significant relationships were observed between RHL_{FCE} and the relative glance metrics (Table X3).

Table X3 Correlations between the glance metric differences in the rural vs. urban environments and participants' relative change between high and low perceptual load flanker compatibility effects for participants who glanced toward the irrelevant stimuli

	RHL_{FCE}	
	Correlation coefficient	*p*
Number of glances (Spearman): difference between rural and urban environments	r(22) =.22	.32
Total duration of glances (Spearman): difference between rural and urban environments	r(10) =.27	.39
Average duration of glances (Spearman): difference between rural and urban environments	r(10) =.24	.46
Average glance initiation time (Spearman): difference between rural and urban environments	r(10) = .20	.53
Distractor rating differences (Spearman): difference between rural and urban environments	r(22) = .36	.08

Appendix Y: Descriptive statistics for lead vehicle braking metrics

Response time until accelerator completely released for 96 aggregated braking samples

ART	**DISTRACTION**		**BASELINE**		**ALL**	
	Mean (ms)	*SD (ms)*	*Mean (ms)*	*SD (ms)*	*Mean (ms)*	*SD (ms)*
RURAL	988	396	836	274	912	345
URBAN	870	249	750	240	810	249
ALL	929	332	793	258	NA	NA

Brake transition time for 96 aggregated braking samples

BTT	**DISTRACTION**		**BASELINE**		**ALL**	
	Mean (ms)	*SD (ms)*	*Mean (ms)*	*SD (ms)*	*Mean (ms)*	*SD (ms)*
RURAL	459	336	473	377	466	353
URBAN	473	305	480	298	476	298
ALL	466	317	476	336	NA	NA

Response time until brake contacted for 96 aggregated braking samples

BRT	**Distraction**		**Baseline**		**ALL**	
	Mean (ms)	*SD (ms)*	*Mean (ms)*	*SD (ms)*	*Mean (ms)*	*SD (ms)*
RURAL	1446	578	1308	498	1377	539
URBAN	1343	449	1229	455	1286	451
ALL	1395	515	1269	474	NA	NA

Gap time for 96 aggregated braking samples

GAP TIME	**DISTRACTION**		**BASELINE**		**ALL**	
	Mean (s)	*SD (s)*	*Mean (s)*	*SD (s)*	*Mean (s)*	*SD (s)*
RURAL	2.66	1.04	2.66	1.11	2.66	1.07
URBAN	2.63	1.12	2.62	1.14	2.62	1.12
ALL	2.64	1.07	2.64	1.12	NA	NA

Maximum deceleration for 96 aggregated braking samples

MAXIMUM DECELERATION	DISTRACTION		BASELINE		ALL	
	Mean (m/s^2)	*SD* (m/s^2)	*Mean* (m/s^2)	*SD* (m/s^2)	*Mean* (m/s^2)	*SD* (m/s^2)
RURAL	-5.5	1.5	-5.1	1.1	-5.3	1.3
URBAN	-5.9	1.8	-5.8	1.7	-5.9	1.7
ALL	-5.7	1.7	-5.5	1.5	NA	NA

Minimum time to collision for 96 aggregated braking samples

TTC_{min}	DISTRACTION		BASELINE		ALL	
	Mean (s)	*SD (s)*	*Mean (s)*	*SD (s)*	*Mean (s)*	*SD (s)*
RURAL	3.43	1.21	4.00	1.31	3.71	1.28
URBAN	2.81	1.17	2.77	1.16	2.79	1.15
ALL	3.12	1.22	3.39	1.37	NA	NA

Perception time for 95 aggregated braking samples

PT	DISTRACTION		BASELINE		ALL	
	Mean (ms)	*SD (ms)*	*Mean (ms)*	*SD (ms)*	*Mean (ms)*	*SD (ms)*
RURAL	503	418	663	605	585	523
URBAN	498	336	490	505	494	421
ALL	501	375	581	560	NA	NA

Inspection time for 84 aggregated braking samples

IT	DISTRACTION		BASELINE		ALL	
	Mean (ms)	*SD (ms)*	*Mean (ms)*	*SD (ms)*	*Mean (ms)*	*SD (ms)*
RURAL	720	300	617	287	700	295
URBAN	625	196	564	191	594	194
ALL	673	255	590	241	NA	NA

Response time until accelerator completely released for 265 single braking samples

ART	DISTRACTION		BASELINE		ALL	
	Mean (ms)	*SD (ms)*	*Mean (ms)*	*SD (ms)*	*Mean (ms)*	*SD (ms)*
RURAL	966	495	833	380	898	443
URBAN	853	365	721	290	788	335
ALL	907	435	777	341	NA	NA

Brake transition time for 265 single braking samples

BTT	DISTRACTION		BASELINE		ALL	
	Mean (ms)	*SD (ms)*	*Mean (ms)*	*SD (ms)*	*Mean (ms)*	*SD (ms)*
RURAL	429	329	443	356	436	342
URBAN	459	346	449	380	454	362
ALL	445	337	446	366	NA	NA

Response time until brake contacted for 265 single braking samples

BRT	DISTRACTION		BASELINE		ALL	
	Mean (ms)	*SD (ms)*	*Mean (ms)*	*SD (ms)*	*Mean (ms)*	*SD (ms)*
RURAL	1395	615	1276	569	1334	593
URBAN	1312	537	1169	481	1242	513
ALL	1352	576	1223	528	NA	NA

Gap time for 265 single braking samples

GAP TIME	DISTRACTION		BASELINE		ALL	
	Mean (s)	*SD (s)*	*Mean (s)*	*SD (s)*	*Mean (s)*	*SD (s)*
RURAL	2.53	1.04	2.58	1.16	2.56	1.10
URBAN	2.58	1.12	2.46	1.13	2.52	1.12
ALL	2.56	1.08	2.52	1.14	NA	NA

Maximum deceleration for 265 single braking samples

MAXIMUM DECELERATION	**DISTRACTION**		**BASELINE**		**ALL**	
	Mean (m/s^2)	*SD* (m/s^2)	*Mean* (m/s^2)	*SD* (m/s^2)	*Mean* (m/s^2)	*SD* (m/s^2)
RURAL	-5.6	1.9	-5.1	1.4	-5.4	1.7
URBAN	-5.9	2.0	-6.0	2.0	-5.9	2.0
ALL	-5.8	1.9	-5.5	1.7	NA	NA

Minimum time to collision for 265 single braking samples

TTC_{min}	**DISTRACTION**		**BASELINE**		**ALL**	
	Mean (s)	*SD (s)*	*Mean (s)*	*SD (s)*	*Mean (s)*	*SD (s)*
RURAL	3.32	1.42	3.96	1.49	3.64	1.49
URBAN	2.78	1.24	2.62	1.21	2.70	1.22
ALL	3.04	1.35	3.29	1.51	NA	NA

Perception time for 248 single braking samples

PT	**DISTRACTION**		**BASELINE**		**ALL**	
	Mean (ms)	*SD (ms)*	*Mean (ms)*	*SD (ms)*	*Mean (ms)*	*SD (ms)*
RURAL	524	484	720	788	625	663
URBAN	480	354	530	620	506	506
ALL	503	424	629	715	NA	NA

Inspection time for 151 single braking samples

IT	**DISTRACTION**		**BASELINE**		**ALL**	
	Mean (ms)	*SD (ms)*	*Mean (ms)*	*SD (ms)*	*Mean (ms)*	*SD (ms)*
RURAL	686	450	618	413	653	432
URBAN	626	243	536	223	583	237
ALL	655	358	576	330	NA	NA

Appendix Z: Experiment 2 detailed lead vehicle braking models

Table Z1 Relationships between factors of interest (distraction and environmental conditions) and driving metrics in response to lead vehicle braking events using linear mixed-effects models. Gap time between the lead vehicle and the participant's vehicle is used as a covariate. Terms in grey were removed from the final models

Response variable	Gap time		Distraction		Environment	
	F-value	*p*	F-value	*p*	F-value	*p*
ART	F(1,69) = 29.99	<.0001	F(1, 69) = 14.39	.0003	F(1, 69) = 6.07	.02
BTT	F(1, 69) = 56.04	<.0001	F(1, 69) = 0.08	.78	F(1,69) = 1.62	.21
BRT	F(1,68) = 87.10	<.0001	F(1, 68) = 12.47	.0007	F(1, 68) = 1.70	.20
TTC$_{min}$	F(1, 67) = 42.36	<.0001	F(1, 67) = 13.18	.0005	F(1, 67) = 59.55	<.0001
Maximum deceleration	F(1, 68) = 47.21	<.0001	F(1, 68) = 2.08	.15	F(1, 68) = 17.67	.0001
PT	F(1, 57) = 9.31	.004	F(1, 57) = 0.61	.44	F(1, 57) = 0.63	.43
IT	F(1, 68) = 14.28	.0003	F(1, 68) = 4.75	.03	F(1, 68) = 1.14	.29

Distraction * Environment		Gap Time * Environment		Gap Time * Distraction		Gap Time* Distraction * Environment	
F-value	*p*	F-value	*p*	F-value	*p*	F-value	*p*
ART continued… F(1, 66) = 0.01	.92	F(1, 68) = 1.20	.28	F(1,67) = 0.39	.54	F(1, 65) = 0.29	.59
BTT continued… F(1, 66) = 0.003	.96	F(1,68) = 0.56	.46	F(1, 67) = 0.07	.80	F(1, 65) = 0.03	.86
BRT continued… F(1, 66) = 0.006	.94	F(1, 68) = 4.45	.04	F(1, 67) = 0.22	.64	F(1, 65) = 0.04	.84
TTC$_{min}$ continued… F(1, 67) = 7.29	.009	F(1, 67) = 15.48	.0002	F(1, 66) = 1.01	.32	F(1, 65) = 0.13	.72
Maximum deceleration continued… F(1, 66) = 1.83	.18	F(1, 68) = 9.87	.003	F(1, 67) = 1.99	.16	F(1, 65) = 0.16	.69
PT continued… F(1, 55) = 0.49	.49	F(1, 54) = 0.34	.56	F(1, 56) = 1.11	.30	F(1, 53) = 0.03	.86
IT continued… F(1, 65) = 0.59	.44	F(1, 67) = 1.39	.24	F(1, 66) = 1.28	.26	F(1, 64) = 1.62	.21