MULTIPLE ALARMS AND DRIVING SITUATIONAL AWARENESS

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1 INTRODUCTION

1.1 Background

There is increasing interest in actively mitigating safety in vehicles beyond that of improving crash worthiness. According to the National Highway Transportation Safety Administration (NHTSA), there are more than 40,000 deaths on highways each year. This number may be decreasing with increasing active public concern and awareness for the use of safety restraints, but the numbers are still in excess of 40,000 deaths annually. Focusing on crash-worthiness as a measure of safety in vehicles will eventually reach a point of diminishing return, thus there is a need for automotive manufacturers to shift their safety focus to crash avoidance safety systems (Runge, 2002).

In the public domain, significant progress and advancements have been made under the Intelligent Vehicles Initiative (IVI) set up by U.S. Department of Transportation to prevent motor vehicle crashes by assisting drivers in avoiding hazardous mistakes (U.S DOT, 1998). One IVI focus area is facilitating the rapid deployment of Collision Avoidance Systems (CAS) in vehicles. Collision Avoidance Systems are a subset of Advanced Vehicle Control Safety Systems (AVCSS) which come under the umbrella of Intelligent Transportation Systems (ITS). These Collision Avoidance Systems warn drivers of imminent collisions and can potentially help to save lives. Primary directions of research in CAS are determining implementation strategies and technologies in vehicles and roadway infrastructure, as well as optimizing the driving performance of different populations of drivers when using CAS.

In CAS implementation, vehicles will communicate with other vehicles as well as with the roadway infrastructure via sensors and telecommunication networks. The data obtained can then be used in Collision Avoidance Systems. Vehicle-to-vehicle CAS include warnings that trigger when a vehicle is about to collide with another vehicle. Examples include Frontal Warning, Rear Warning and Blind Spot Detection Warnings. Vehicle-to-infrastructure CAS include warnings that trigger when a vehicle is about to have a collision with the roadway infrastructure. Examples include Intersection Warnings, Lane Departure Warnings, Curve Speed Warnings and Road-condition Warnings.

Driving in a dynamic environment has become increasingly complex, such that drivers must visually track objects, monitor a constantly changing system, manage system information, to include the explosion of telematics, and make decisions in this dynamic and potentially high mental workload environment. Introducing Collision Avoidance Systems into vehicles could add to the complexity of this dynamic environment as different drivers will respond differently to Collision Avoidance Systems and there are many critical human factors issues that require investigation.

1.2 Motivation & Objectives

Many studies have been conducted to determine the effectiveness of CAS on warning drivers of impending collisions. Studies include examining effectiveness of CAS on differing age groups(Maltz, Sun & Mourant, 2004), as well as on presenting alarm warnings through different modalities like through the aural (Graham, 1999), visual (General Motors Corporation & Delphi-Delco Electronic Systems, 2002) and haptic channels (Lee & Hoffman, 2004). However, no study directly compared the braking reaction time between all three channels for different age groups of drivers, and preliminary studies showed that more research had to be conducted in order to come to a definite conclusion. In addition, no research has been published investigating how the interactions of different warnings of the differing CAS affect human performance and situational awareness for differing age groups of drivers.

Research has been conducted in the aviation domain with respect to cognitive saturation onboard the cockpit and aural alarms. The application of communications and information technology in modern cockpits has resulted in sophisticated automation in flying. Modern planes are flown primarily using automation with the pilots acting as supervisory controllers. This has given rise to a plethora of human factors issues such as mode confusion when the pilot is unaware of the level of automation and the state of the plane. In particular onboard Traffic Alert and Collision Avoidance Systems (TCAS II), meant to resolve traffic conflicts between two aircrafts by alerting pilots to an imminent collision with another object has also given rise to many cognitive saturation and confusion problems (Schnell, 2005).

Like flying, driving is an activity that demands both tracking and monitoring skills. While a driver is less of a supervisory controller than a pilot in a fly-by-wire cockpit, with the rapid confluence of sensor, communications, and information technology in a car cockpit, drivers will be faced with similar cognitive saturation issues. One human factors problem that will likely arise involves the warning alarms of Collision Avoidance Systems. Problems in alarm systems that give rise to human factors issues include nuisance alarms, ambiguous alarms, alarm inflation, etc. It is important that alarms are informative in alerting humans to the condition at hand, without overwhelming them with too much or inadequate information. Such information may be embedded in the nature of the alarm (i.e. a speech warning), or may come from the humans being aware of the context (Woods, 1995).

Of particular interest in this study is whether or not a single master alarm warning versus multiple warnings for the different CAS systems conveys adequate information to the drivers. In addition, nuisance alarms and alarm saturation may adversely affect the way humans react to true alarms. Thus, a problem of trust and reliability of the warning systems arises, which is a known problem when human interact with automated systems (Lee, 2004).

Through this preliminary pilot study, some of the critical questions to be answered include:

1. Do multiple alarms for different CAS as opposed to a single master alarm affect drivers' recognition, performance, and action when they experience an imminent collision?
2. Is driver performance under the two different alarm conditions affected by cognitive distraction?

This report and investigation is limited by the following boundaries:

- Warnings were presented to drivers through the *aural channels* only
- CAS systems investigated include Frontal CAS, Rear CAS, and Lane Departure Warning System only

2 METHODS

2.1 Experiment Apparatus

2.1.1 Simulator Hardware – Miss Daisy

The experiment was conducted in MIT AgeLab's Driving Simulator, named "Miss Daisy". It is a real but static 2001 Volkswagen™ Beetle, which is fully instrumented with the engine removed. There is also no rearview mirror; however, it is provided via simulation.

Using STISIM™, subjects drive through programmed scenarios, interfacing with the brake pedal, accelerator pedal and steering wheel, which provide force feedback for an increased degree of realism. Speedometers, turning signals, hazard lights, seat adjustments, air conditioning are fully functional. Subjects hear audio sounds, namely engine, tires, crashes, as well as the pertinent alarm warnings through the in-car radio sound system. On the right side of the driver is an additional small screen with a number keypad connected. This side screen can be used to create distraction tasks for the subjects while driving. The simulation is projected onto a large wall-mounted eight feet by six feet projector screen six feet in front of the driver that provides approximately a 30° horizontal field of view. Figures 1, 2, and 3 are external and internal pictures of "Miss Daisy".

Figure 1: Exterior View of Miss Daisy Beetle

Figure 2: Interior of Miss Daisy-Driver's Interface & Internal Screen

Figure 3: Steering Wheel Interface & Functional Speedometer

2.1.2 Simulator Software – STISIM

The software used in this study was STISIM™ Drive Build 2.06.00 by Systems Technology Inc. Scenarios were built using the Scenario Definition Language (SDL) and necessary modifications were made using the STISIM™ Drive Open Module (OM) code using Visual Basic. Modifications to the OM code for this investigation included coding the algorithms for the triggering of the three different Collision Avoidance Systems – Frontal Collision Warning System, Rear Collision Warning System, and Lane Departure Warning System, as well as for writing output to a data text file to collect subjects' reaction time information.

Figure 4 shows an example of the real-time data display that runs during the experiment. Pertinent information includes distance that the subject driver has completed, the current speed, as well as the steering, throttle and braking input counts.

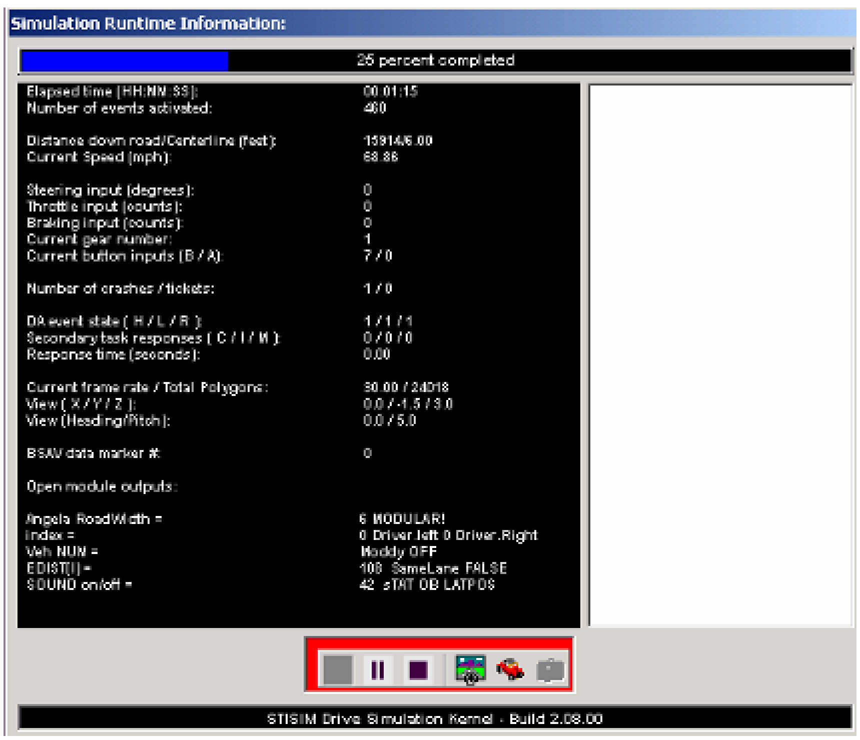

Figure 4: Real-Time Data Display During Experiment Run

2.2 Experiment Design Overview

To address the questions in the previous motivation section, an experiment was designed with three factors. These three factors in the experiment design are illustrated in Figure 5.

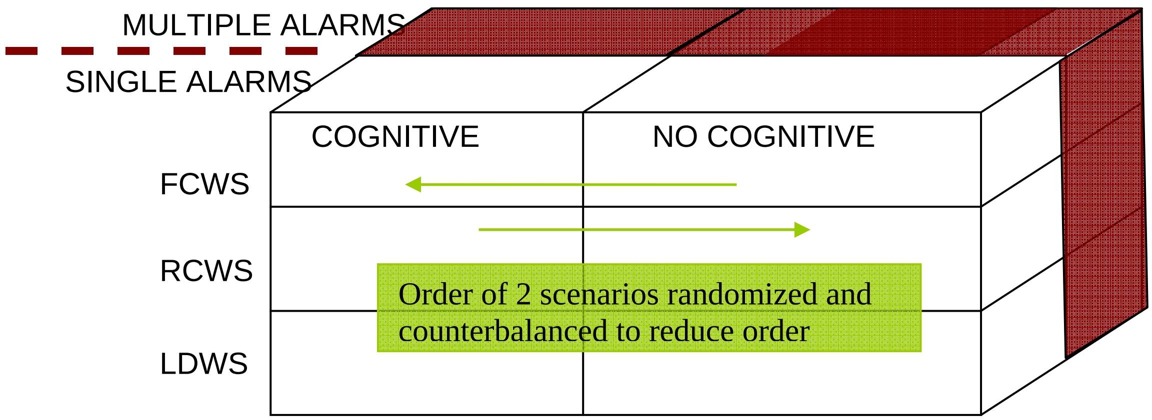

Figure 5: The 2x2x3 Experiment Design

The first factor, alarm type (single vs. multiple), was a between–subjects factor. Half of the subjects drove through the programmed SDL scenarios and heard a single master alarm sounding for all the 3 types of Collision Avoidance Systems, while the other half heard different alarms play for each of the 3 CAS events.

The second factor was the type of CAS events, which were:

1. FCWS: Frontal Collision Warning System
2. RCWS: Rear Collision Warning System
3. LDWS: Lane Departure Warning System

This factor was repeated throughout the experiment, and every subject experienced all 3 CAS events.

The third factor was the presence of a cognitive load task, to provide distraction to the driver while they were driving. This task was presented on an internal side screen in the car (see Figure 2*)* and provided a means to distract drivers from the primary task since they had to look to the screen in order to complete the secondary cognitive load task.

The primary dependant variable in the experiment was the reaction time of the driver to take a corrective action from the triggering of the event alarm. For example, for an FCWS event, the reaction time was calculated as the difference in time from when the alarm was triggered to the time a corrective action was taken by the driver. This corrective action was the instant the brake pedal was applied for frontal collisions, the steering correction was made for lane deviation alerts, or when the accelerator gas pedal was engaged for potential rear collisions. Secondary dependant variables included the number of crashes as well as the score obtained on the cognitive load task.

2.3 Collision Warning Algorithms

2.3.1 Frontal Collision Warning System

The FCWS algorithm was triggered based on violating a minimum separation, as well as closing relative velocity. The minimum separation was 100 feet, and once this minimum separation was violated, the algorithm checked for the relative velocity. If the relative velocity of the driver's car was positive with respect to the frontal object (either a moving vehicle, or a static object), the alarm warning was then triggered.

2.3.2 Rear Collision Warning System

The RCWS algorithms worked similar to the FCWS, in that violating the minimum separation of 100 feet, as well as closing relative velocity of the driver with respect to the rear event triggered the rear warning alarm.

2.3.3 Lane Departure Warning System

The LDWS algorithm was triggered when the driver's vehicle crossed the lane-markers. However, to mitigate the problem of the alarm sounding every time the driver crossed the lane, an additional metric was programmed and the alarm would only sound if the turning signals were not activated. This was a way to force the alarm to sound on *unintentional* departing from the lanes.

2.4 Collision Warning Triggering Events

The following events illustrate how the particular alarm was triggered for the three CAS systems. Refer to Appendix D and E for the screenshots for the frontal and rear triggering events. However, some problems surfaced during the experiments, which will be addressed in the "Discussion" section.

2.4.1 Frontal Collision Warning System

There were five types of FCWS triggering events as listed below:

1. Oncoming vehicle on highway that overtakes another car, resulting in an impending head-on collision. The head-on incoming car does not swerve back into its own lane.
2. Lead vehicle on highway that brakes suddenly.
3. Stationary parked vehicle that pulls out from the side of the road into the driver's path.
4. Stationary parked vehicle that backs out from a garage onto the driver's path, and then backs into the garage again.

5. A tree fallen across the driver's lane and the driver is forced to swerve to avoid a collision. The tree appears at the top of a vertical curvature segment of the road, and so prevents the driver from seeing the object too early.

2.4.2 Rear Collision Warning System

There was basically one type of RCWS triggering event which was a vehicle that quickly approached the driver from the rear, with a closing velocity of 50 feet/second more than the speed of the driver. There were two ways by which the other vehicle could retreat at the last moment without crashing into the subject driver:

1. The moving rear vehicle surges up to the driver, and then backs off at the last moment when the 2 vehicles are within 2 feet of each other.
2. The moving rear vehicle surges up to the driver, and then overtakes on the driver's left when the 2 vehicles are within 2 feet of each other. .

2.4.3 Lane Departure Warning System

Of the three types of Collision Avoidance Systems under examination, the LDWS was the hardest to replicate in an experimental setting. The main difficulty was inducing and forcing a lane change on the subjects and measuring their responses to the alarm. In the real world, Lane Departure Warnings are useful for drivers who fall asleep at the wheel. However, such a scenario is not practical to reliably reproduce during a controlled experimental testing session.

STISIM™ comes equipped with a "Wind Gust" event and this was one way to force a lane change maneuver on the drivers. Thus, the LDWS was designed to trigger via a "windy" condition. Five random wind events of varying strength were programmed into each testing scenario, forcing subjects off their path. This windy condition would be present for a random length of time ranging from 2-5 seconds.

2.5 Collision Warning Alarm Sounds

Warning alarms were presented to the subjects through the aural channel. The alarm sound files are hyperlinked to the document.

For the single master alarm warning scenarios, participants heard a "Hazard, hazard" warning sound that was triggered based on the aforementioned algorithms.

For the multiple alarm warning scenarios, participants heard the following alarms

- FCWS: "Warning, warning"
- RCWS: "Hazard hazard"
- LDWS: beeps

2.6 Cognitive Load Task

A secondary workload task, termed the cognitive load task, was included as a distraction to direct driver's attention away from focusing on the driving scenarios, which is an ever-increasing problem in actual driving due to the popularity of telematics in vehicles.

During the cognitive load task, five numbers would flash on the internal side screen at a constant rate (Figure 11). Out of this string of five numbers, there would be four zeros and one non-zero number. The subject was required to enter the *position* of the non-zero number on the number keypad located just below the internal screen. For example, if the string displayed was "***1 0 0 0 0***", the correct answer was 1. However, if the string displayed was "***8 0 0 0 0***" instead, the correct answer was still 1, and not 8. The cognitive load task was designed to update every 500 milliseconds.

Figure 6: Cognitive Load Task with Number Keypad Shown

2.7 Procedure

The experiment lasted approximately 50 minutes in total. Subjects filled out a COUHES-approved consent form (Appendix A), and a pre-simulation survey (Appendix B*)*. The pre-survey assessed subjects' demographical data, driving history information especially with regard to past experiences with collisions, and their tendency for getting motion sickness as well as experience playing video games.

Subjects were then seated in "Miss Daisy", and allowed to familiarize themselves with the interface of the car. In order to reduce any variability between subjects with respect to instructions, subjects subsequently heard pre-recorded instruction files (the sound files are as hyperlinked and are arranged in numerical order) played on the in-car sound system. Subjects were told to drive as they normally would, obeying speed limits and traffic control devices like stop signs and intersection lights.

The experiment was divided into two segments, 1) the training and 2) testing sessions. Only daylight and dry road conditions were simulated. For the two training sessions that lasted 10 minutes in total, subjects acclimated to the simulator in an urban setting followed by a mountainous road. Pertinent snapshots from these two training sessions can be found in Appendix F. The purpose of including the mountainous road training session was to ensure that subjects were comfortable with the handling qualities in turns of sharp turns, as it was a necessary skill for the LDWS condition. In addition, subjects practiced driving down a straight road while executing the cognitive load task.

In both training sessions, deliberate events that triggered the FCWS, RCWS and LDWS were used to acclimatize the subject to the warning alarms before the actual testing sessions. Half of the subjects under the multiple alarm factor heard the corresponding alarms for the type of scenarios, while those under the single alarm factor heard the same alarm sound throughout. The events that triggered these alarms were the same across the alarm type factor to maintain consistency between the subjects who heard multiple alarms vs. those who heard the single alarm.

In the subsequent two testing scenarios, subjects were required to drive through approximately 42,000 feet of roadway, consisting of a section of highway, a housing estate, where their speed limit was decreased, and finally on a highway section again. In each testing scenario, there were 5 FCWS, 5 RCWS and 5 LDWS events, presented in randomized order throughout the test session. In addition, the order in which subjects drove with the cognitive load task was also counterbalanced. After subjects completed the complete testing sessions, they filled out a post-simulation survey (Appendix C).

2.8 Subjects

19 licensed drivers volunteered to participate in this experiment: 3 females and 16 males. Subjects' ages ranged from 22 to 53 and were affiliated with MIT either as students or staff and all were volunteers. Three subjects dropped out due to nausea and feeling unwell: one female, and two males. The first dropped out after the first urban practice scenario, the second dropped after the first testing scenario and the last dropped out before the end of the second testing scenario.

3 STATISTICAL RESULTS

The questions under investigation are:

1. Is there a difference in drivers' reaction times to multiple warning alarms versus a single master warning alarm?
2. Is there a difference in drivers' reaction times under the distracted state versus when they are not distracted?
3. Is there a difference in drivers' reaction times to the 3 types of CAS?

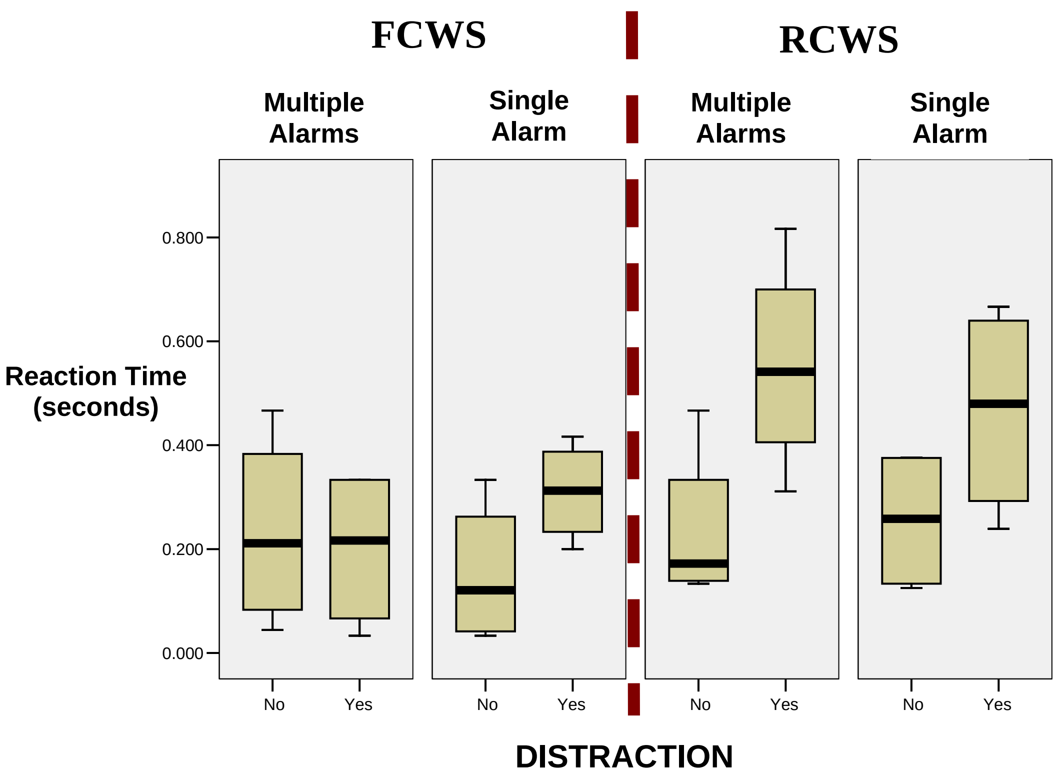

Figure 7: Boxplots for Three Experimental Factors

In the analysis of the data, the LDWS factor level was dropped due to the inability to obtain consistent results across subjects. Despite pre-testing, the induced wind events did not produce the desire result of forcing subjects out of their lanes, whether while they were in the distracted or aware state. Subjects generally were able to successfully maintain their cars in the lanes despite the external influences. In addition, according to the results asked of the post-survey of the 16 participants, none found it hard to control the steering of the vehicle during the induced wind gusts events. This will be addressed further under the "Discussion" and "Future Work" sections.

From the boxplots in Figure 12, it appears as if the alarm type condition produces different results as well as the state of distraction. There seems to be a difference in subjects' reaction times when they are doing a cognitive load task versus when they are just driving. In addition, there is a slight indication that subjects take longer to react to a RCWS event than to a FCWS event. The largest discrepancy in reaction time occurs under the rear collision event when subjects are distracted. This discrepancy in time applies under both the Multiple Alarms as well as Single Alarm condition.

Statistical Analysis:

Table 1 details the results from 2*2*2 (with data from LDWS dropped) mixed repeated measures ANOVA model. All data met normality and homogeneity assumptions. All alpha values = .05.

Table 1: ANOVA Results

Tests of Between-Subjects Effects

Dependent Variable: time

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	Hypothesis	2.893	1	2.893	173.155	.000
	Error	.100	6	.017(a)		
cogload * alarmtype	Hypothesis	.081	1	.081	2.570	.125
	Error	.602	19	.032(b)		
cogload * alarm_no	Hypothesis	.004	1	.004	.119	.734
	Error	.602	19	.032(b)		
alarmtype * alarm_no	Hypothesis	.005	1	.005	.150	.703
	Error	.602	19	.032(b)		
cogload	Hypothesis	.214	1	.214	6.741	.018
	Error	.602	19	.032(b)		
alarmtype	Hypothesis	.188	1	.188	5.948	.025
	Error	.602	19	.032(b)		
alarm_no	Hypothesis	.001	1	.001	.045	.839
	Error	.100	6	.017(a)		
subject(alarm_no)	Hypothesis	.100	6	.017	.527	.781
	Error	.602	19	.032(b)		

a MS(subject(alarm_no))
b MS(Error)

According to the results, the Cognitive Load (Not Distracted/Distracted) and Alarm Type (FCWS/RCWS) factors were significant, with $p = 0.018$ and $p = 0.025$ respectively. Alarm Number (single/multiple) was not significant ($p = 0.839$) and neither were the interactions between Alarm Number and the other 2 factors. The 95% confidence intervals of the Cognitive Load and Alarm Type factors are as shown in Tables 2 and 3.

Table 2: 95% CI for Alarm Type (FCWS/RCWS)

alarmtype	Mean	Std. Error	df	95% Confidence Interval	
				Lower Bound	Upper Bound
1	.224	.038	11.154	.141	.307
2	.377	.046	10.808	.276	.479

a Dependent Variable: time.

Table 3: 95% CI for Cognitive Load (Not Distracted/Distracted)

cogload	Mean	Std. Error	df	95% Confidence Interval	
				Lower Bound	Upper Bound
1	.219	.040	11.734	.132	.306
2	.382	.044	9.918	.284	.481

a Dependent Variable: time.

4 DISCUSSION

4.1 Research Objectives

To recapitulate, the questions under investigation in this pilot study are:

1. Is there a difference in drivers' reaction times to multiple warning alarms versus a single master warning alarm for different alarm warning systems?
2. Is there a difference in drivers' reaction times under the distracted state versus when they are not distracted?
3. Is there a difference in drivers' reaction times to the 3 types of CAS?

I will now proceed to address these three research questions, as supported by the statistical results as well as post-survey findings.

4.1.1 Multiple vs. Single Master Warning Alarm

According to the results of the data analysis, there was *no* significant difference in drivers' reaction times under the different Alarm Types. This is interesting, since it may mean that whether hearing either the same alarms or different alarms for different types of warning systems does not have a significant impact on reaction time of drivers. Nevertheless, it should be kept in mind that there were only three types of CAS investigated in this pilot study, out of which the results of one of the CAS were dropped. Hence, for such a small number, perhaps having multiple alerts did not matter, but future vehicles with CAS will likely include more than these three warning systems.

In addition, according to the post survey question #12 asked with regard to preference for the different types of alarms, the results are summarized in Table 4.

Table 4: Preference for Alarms

Preference For Alarms			
Type of alarms:	*Types of CAS:*		
	FCWS	***RCWS***	***LDWS***
Voice	75% "Front, front"	75% "Rear, rear"	58.33% "Lane, lane"
Beeps	25%	25%	33.33%
No Alert	-	-	8.33%

Out of the subjects who answered the question, 75% preferred having different alarms for the FCWS and RCWS that is distinguished by a voice alert, specifying "Front, front" and "Rear, rear". The remaining 25% preferred beeps for the FCWS and RCWS alarms. As for the LDWS systems, 33.33% of subjects who answered the question preferred beeps for the alarm, while 58.33% preferred a voice alert. 8.33% of subjects did not want any alarm at all for the LDWS system.

4.1.2 Driving under distraction

According to the results of the data analysis, there was a significant difference in drivers' reaction times when they were driving while distracted with doing the cognitive load task.

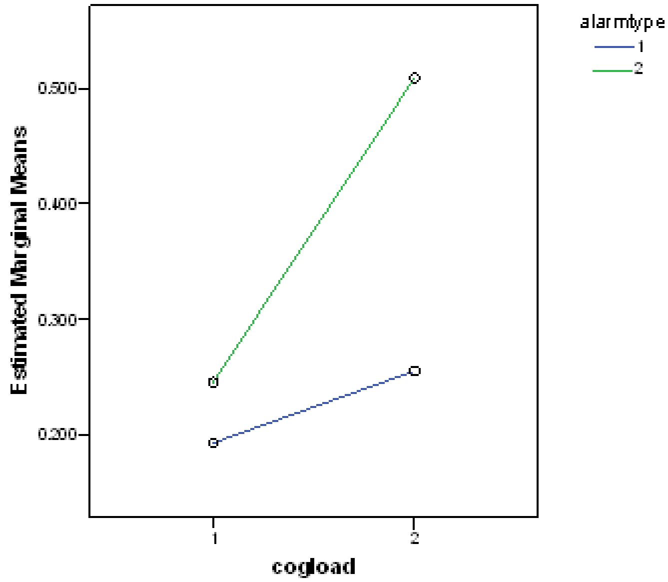

Figure 8: Cognitive Load vs. Alarm Type Factor (FCWS (1)/RCWS (2)).

Figure 13 demonstrates that driving while doing the secondary load task (condition #2) always yielded a higher reaction time to the alarms than without (condition #1) ,which was particularly significant for the rear collision warning. This result is expected, as there have been numerous studies that demonstrate degraded driver performance under secondary task distraction like the use of mobile phones, in-car navigational systems, and entertainment systems while driving (Young, Regan & Hammer, 2003). However, of particular interest is the sharp increase in reaction time under a cognitive load that RCWS produced. This is likely due to conflict in cognitive resource allocation. It is more difficult in general to spatially orient to events happening in mirrors due to the mapping transformation required, and when cognitive loaded with an additional task, spare mental capacity is significantly reduced.

Subjects were asked whether the alarms were helpful in helping them avoid a frontal collision, a rear collision, or to keep in their own lane while they were distracted with doing the cognitive load task (questions #7 and #8 in the post-survey). The results are summarized in Table 5.

Table 5: Helpfulness of Alarms Survey

Driving While Distracted		
Were alarms helpful in:	*Yes*	*No*
Avoiding a Frontal Collision	53%	47%
Avoiding a Rear Collision	81%	19%
Keeping in own lane	53%	47%

From the survey findings, more than half of the subjects found the three types of alarms helpful when they were distracted while driving. The findings of the post-survey correspond with the statistical results obtained in that 81% of subjects found that the RCWS alarm was helpful, especially when they were distracted. A marginally greater number of subjects (53%) found that the FCWS alarms and LDWS alarms were helpful when they were cognitively loaded with other tasks.

Similarly, post-driving survey questions #5 and #6 asked about the helpfulness of alarms, when the subjects were only tasked with driving. Table 6 summarizes the results.

Table 6: Helpfulness of Alarms When Not Distracted

Driving While NOT Distracted		
Were alarms helpful in:	*Yes*	*No*
Avoiding a Frontal Collision	40%	60%
Avoiding a Rear Collision	73%	27%
Keeping in own lane	40%	60%

Overall, the percentage of subjects who found the three different alarms useful when not under a cognitive load decreased, although more than half of the subjects still found that RCWS alarm helpful. On the contrary, only 40% found the FCWS and LDWS alarms helpful.

Again, the findings from the survey supports the statistical results obtained that a secondary distraction load task has a significant effect on increasing drivers' reaction times to respond to alarm warnings.

4.1.3 Different Warning Systems

According to the results of the data analysis, there was a significant difference in drivers' reaction times to the different Collision Avoidance Systems. As discussed previously, due the need to mentally transform images seen in a mirror in reverse to adhere to a person's mental model of a potential collision situation, which is not needed for a frontal collision, it takes people longer to realize what is happening.

From Tables 5 and 6, 53% and 40% of the subjects felt that the FCWS alarms were helpful in alerting them to impending collisions while they were and were not distracted, respectively. Similarly, 81% and 73% felt that the RCWS alarms were helpful in alerting them to impending collisions, in similar conditions. This preference for the RCWS alarm, especially under cognitive distraction, is likely due to the desire to cognitively offload the rearview monitoring task. This is an important finding because under distraction, subjects fixated on the frontal view as it takes less cognitive resources. These spare resources are then used for their secondary task such as talking on a cell phone. This is an example of cognitive parsimony and further evidence that for events that are not taking place in the frontal view, drivers need alarm devices for situational awareness.

Out of the remaining subjects who did not find the alarms helpful to post-survey questions #5-#8, the results of the subjects' responses to question #11 are summarized in Table 7.

Table 7: Summary of Subjects' Negative Responses to 3 Alarms

Types of Negative Responses To 3 Alarm Warning Systems			
Subjects who found alarms…	*FCWS*	*RCWS*	*LDWS*
Ineffective and Neutral	**55%**	25%	13%
Annoying	27%	**50%**	**85%**
Stressful	36%	25%	13%
Confusing	-	25%	20%
Distracting	-	25%	40%

55% of subjects found the FCWS alarm ineffective and neutral. This is largely attributed to the fact that the subjects saw the event happening before the alarm sounded. This would also explain why there was a difference in reaction times to FCWS events versus RCWS events.

An interesting point to note is that a high percentage (85%) of subjects found the LDWS alarm annoying. This is largely due to the fact that the alarm went on even though subjects were intentionally changing lanes to avoid a frontal or rear collision. Thus, ways to mitigate this problem will be addressed in "Future Improvements" section.

4.2 Limitations of hardware and software

4.2.1 Lack of Turning Signals of other vehicles

There is no way of indicating turning signals on the virtual SDL cars in the scenarios. This is a limitation since the driver has no way of knowing what the other programmed vehicles in the scenarios intend to do. Many subjects were frustrated since they did not know the intention of the other cars in the scenarios. This was especially true in the case of an impending rear collision when drivers didn't know if the rear vehicle following was intending to pass on the left or not. In addition, because there is only a 90-degree field-of-view for the drivers, subjects did not know if the rear vehicle was passing them. However, drivers in real life often do not use turning signals, so it can be argued that although this is a limitation from the experiment apparatus, it is an acceptable mimic of real life driving experiences.

4.2.2 Wind induced event triggering the Lane Departure Warning System

One limitation of the systems is that when there is an induced wind event, there is force-feedback from the steering wheel which causes the steering wheel to shake. This is a fundamental problem because the shaking of the steering wheel transmits haptic cues to the drivers, forewarning of an event. The force-feedback is due to the 'steering deadband' on the system. This deadband specifies the bandwidth of tightness with which drivers will experience the steering torque of the steering wheel. This deadband can be adjusted such that the tighter the deadband, the more force-feedback and torque assist drivers will experience, but the more the steering wheel will shake when a wind event occurs. The torque in the steering deadband also assists in correcting the steering change during the induced wind events automatically. Thus drivers experience steering assist and haptic feedback from the steering wheel inadvertently. This can present a problem since it confounds the experimental study of measuring drivers' responses to the Lane Departure Warning System's alarm.

Also, from the post-survey feedback questions, subjects explained that when the wind gust event was simulated, they found it “hard to control direction [of the steering wheel]” and that “the steering wheel felt weird when I tried to compensate for the wind”. This is attributed to the steer assist and haptic torque feedback to the wheel.

4.2.3 Inaccurate Speed Impression

According to the post-survey feedback, many subjects felt that the impression of speed from the simulated drive is inadequate. They often had to look at their speedometer in order to accurately gauge the current speed. As a result, many subjects were driving at a higher speed than they thought they were.

4.3 Effectiveness of the Cognitive Load Task as a distraction tool

Initially, participants felt that it was hard driving as well as performing the secondary task at the same time. However, after practice, participants got used to the task and the task became monotonous after a while. From the post-survey questions #18 and #19 which asked the subjects if they had difficulty maintaining safe driving while doing the number task, all of the subjects felt that driving the test scenario while simultaneously performing the secondary load task affected their driving. The subjects also found that the difficulty of the cognitive load task was just right, albeit a little monotonous. A result of interest to note is that most subjects found that the alarms were helpful in helping them avoid a collision for a rear collision event than in lane keeping and in avoiding the frontal collision event.

5 FUTURE WORK

5.1 Follow-up Experiment

The paper is based on a pilot study conducted to answer the research objectives mentioned in the “Introduction-Motivation and Objectives”. A follow-up, more detailed experiment is planned that will seek to answer the following research questions:

1. Is there a difference in drivers’ reaction times to multiple warning alarms versus a single master warning alarm for different alarm warning systems?
2. Is there a difference in drivers’ reaction times to the 3 types of Collision Avoidance Warning Systems?
3. Is there a difference in drivers’ reaction times to the Collision Avoidance Warning Systems under different alarm system reliabilities?

The factor of cognitive load distraction will be replaced with the other factor of system reliability. A factor of high system reliability includes having a high probability of true positives for alarms, and a low probability of false positives. A less reliable alarm system is a noisy system that would have a high incidence of false positives alarms, and low incidence of true positives for alarms.

5.2 Proposed Improvements for Future Work

5.2.1 Event Triggers

One of the problems that surfaced during the experiment was that the induced wind event was not a good measure of the LDWS. The purpose of putting in a wind event is to cause a controlled lane change event, such that the onset of the event is the same for all subjects.

A few interventions will be investigated to rectify this problem. In the experiment, the magnitude of the wind event was set to be approximately 3-5 out of a scale of 10. One method to force the LDWS to occur would be to increase the magnitude of the wind event closer to 10. However, as mentioned above, in the magnitude of 10, the drivers will experience violent swerving out of their own lane. This presents a couple of problems. First, it could induce nausea and simulator sickness more rapidly than otherwise. Second, a bigger magnitude of wind translates to more force-feedback on the wheel as the simulator tries to ‘self-correct’ and adjusts for the wind event. This will result in more violent shaking of the steering wheel, which can present a haptic confound.

Moreover, from the post-survey question #16 which asked subjects about their impression of the simulated wind conditions, many of the subjects wrote that the simulated windy conditions were “pretty poor simulation”, as it was hard to “predict how the simulator would respond” as well as “very unrealistic”.

Another method to induce a lane departure could instead be a self-programmed induced windy condition that involves a change in the heading of the subjects' car. SDL allows various attributes of the driver's car to be controlled at all times during the simulated run. Thus, the visual change in heading of the car could be obtained by manipulating various variables. Since this induced wind event will be triggered by the code, the steering torque feedback to compensate for the lane change should not be activated, and hopefully, there will be no haptic confound.

5.2.2 Smarter Vehicles:

The frontal and rear warning triggering events seemed effective but more changes need to be made to fine-tune the behavior of the other vehicles. Currently, the other vehicles in the scenario are programmed with pre-defined actions. For example, if the driver approaches within 50 feet of car A, car A will back out from the parking garage. These pre-programmed cars could be further improved to become "smarter" cars that respond to driver's behavior. Because driver behavior is highly variable, narrowly-based algorithms cannot capture all possible events thus more robust algorithms are needed.

5.2.3 Algorithm changes

The LDWS algorithm that was implemented was very simple, based solely on crossing of lane tracks. Intention to change tracks was measured by the presence of activating turning signals. However, when subjects drove, they changed lanes to avoid another frontal or rear collision often, but did not activate the turning signals. According to the post-survey question #11 which asked subjects to elaborate on their negative responses to alarms, 85% of subjects felt that the LDWS was especially annoying and confusing at best, and distracting and stressful at other times, because it sounded even though they were *intentionally* changing lanes to avoid another RCWS or FCWS event (Table 7). A change is needed to make the LDWS algorithm more sophisticated, and based on current algorithms for LDWS in vehicles in the market. Alternatively, more training could be provided to ensure that participants use their turning signals when intentionally changing lanes after the aversion of a collision.

In addition, the FCWS and RCWS algorithm could also be further improved to be more sensitive. From visual observations during the experiment, as well as from participants' comments in post-survey questions #5-#8 which addressed subjects' impressions on the helpfulness of alarms, 60% of the subjects felt that the alarms, especially the FCWS alarm was not helpful when they were not distracted (Table 6). This could be attributed to the fact that the alarm only came on *after* the subject visually saw the event happening. Thus, the alarm did not alert them to it.

5.2.4 Training sessions

According to the post-survey questions #13 and #14 with regard to the length and amount of practice time on both the urban and mountainous training scenarios, all 16 subjects felt that they had sufficient practice time and that the length of both scenarios were appropriate. Since lane keeping is an important skill to have for the LDWS, practicing on curvy roads is a necessary part of training procedure. However, minimizing both the number and severity of curves is warranted so that the probability of getting motion and simulator sickness is reduced.

5.2.5 Subject Prediction

Most of the subjects could not predict when the frontal, rear, or lane departure events were going to occur. However, a few subjects mentioned that they were driving more cautiously since they were expecting something to happen. Also, a few others were able to predict the rear events since all the cars that appeared in the rearview mirror were RCWS events. One way to address this issue is to include more activity in the scenarios, including traffic lights, pedestrians, construction work, as well as more vehicles that do not become RCWS events.

The testing scenarios were designed to be a section of highway, followed by a housing estate, and then a section of highway again, on a one lane road. It was decided against having more than one lane for the driver, since it would be possible that the subject drives on a certain lane, while FCWS and RCWS events were programmed to happen on other lanes. It was also decided against having a purely highway scenario since it would be unrealistic to have stationary cars pull out from the side of the roads. In addition, subjects would be driving at a high speed and so there would be no speed allowance for drivers to speed up to avoid an RCWS event, given the speed limit of approximately 80miles/hour on the Miss Daisy simulator.

5.2.6 Alarm Sounds

Post-survey question #12 asked subjects what types of alarms they would have preferred for the 3 different CAS warning systems. Regardless of whether subjects heard multiple or single alarms, a majority of the subjects suggested that that having different voice alerts saying “Front”, “Rear” and “Lane” would be more helpful (Table 4). For the follow-on experiment, the multiple alerts could be changed to reflect these sounds, or alternatively, we could also use the sounds that are currently being used in vehicles in market.

5.2.7 Experimental Procedure

Most of the subjects felt a degree of unwellness in one way or another according to post-survey question #2 and #3. Considering that the sample population in this pilot study was relatively young, simulator sickness could prove to be a real problem in the follow-on experiment if the sample population were to include an elder population. One way to combat this problem is to break up the length of the testing sessions – from having two 10 minute-long testing sessions each, to having three shorter testing sessions. In this way, participants could take a break between testing sessions.

5.3 Reliability and True vs. False Positives

In the follow-on experiment, an additional factor or reliability ratios will be investigated. Two treatment levels of this factor will be investigated: a ratio of 1:3 and a ratio of 3:1 for True Positives: False Positives.

5.3.1 TP and FP Triggers

The True Positive triggers for the FCWS, RCWS and LDWS events would be as mentioned before. The False Positive triggers would essentially be random soundings of the alarm, when no apparent event takes place.

For each testing scenario, there will be an equal number of FCWS, RCWS and LDWS events randomly interspersed in the driving roadway scenario. Correspondingly, there will also be the appropriate number of False Positive events coded into the testing scenarios for each of these three warning systems in two differing ratios of 1:3 and 3:1. It must be essential that when the False Positive alarm goes off for any of the three warning systems, that none of the True Positive events are scheduled to take place.

5.3.2 TP and FP Response Measurements

The True Positive measurements of the FCWS events would be the reaction time needed to apply brakes. The TP measurements of the RCWS events would be the reaction time needed to apply the throttle, and that of the LDWS would be the reaction time needed to make a steering correction in the opposite direction.

The False Positive measurements would be recognition of the event and the reaction time for the participants to realize that the alarm was essentially a false alarm. If subjects notice that the event was a False Positive event, they would make minimal or no changes to their driving. Thus, we would not expect an immediate change in throttle, brake or steering input counts. As such, I propose that the subjects activate a button to indicate recognition of a false alarm event. An example of such a button might be pressing a button on the side displays used previously for the cognitive load task. In the subsequent statistical analysis, not only will reaction times be analyzed, but also counts of false alarm event recognition, as well as subject frustration levels.

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APPENDIX A: SUBJECT CONSENT FORM

CONSENT TO PARTICIPATE IN NON-BIOMEDICAL RESEARCH

Multiple Warnings and Driver Situation Awareness

You are asked to participate in a research study conducted by Angela Ho and Dr. Mary Cummings from the Department of Aeronautics and Astronautics at the Massachusetts Institute of Technology (M.I.T.). You were selected as a possible participant in this study because you are between the ages of 18 and 55 and hold a valid drivers license. You should read the information below, and ask questions about anything you do not understand before deciding whether or not to participate.

- **PARTICIPATION AND WITHDRAWAL**

Your participation in this study is completely voluntary and you are free to choose whether to be in it or not. If you choose to be in this study, you may subsequently withdraw from it at any time without penalty or consequences of any kind. The investigator may withdraw you from this research if circumstances arise which warrant doing so.

- **PURPOSE OF THE STUDY**

The study is designed to evaluate how different alarms in Collision Avoidance Systems affect human performance.

- **PROCEDURES**

If you volunteer to participate in this study, we would ask you to:

(1) First fill out pre-test questionnaires on your driving tendencies and experiences.
(2) Sit in and drive the vehicle simulator "Miss Daisy" through a virtual environment as part of acclimatizing yourself with the simulator environment for up to 15 minutes.
(3) Various different experimental runs will follow during the next 45 minutes. You will be asked to drive through a series of simulated scenarios which will test your ability to discriminate between different types of aural alarms (forward collision & real collision). Driving data will be collected based on different responses to alarms triggered by the collision avoidance systems.
(4) Lastly, fill out a post-test questionnaire on your simulator experience.

- **POTENTIAL RISKS AND DISCOMFORTS**

There are no major risks anticipated from participation in this study. There is a slight chance of experiencing simulator sickness a similar experience to motion sickness. Please inform the experimentor at the first sign of any discomfort. Should you wish to stop or delay the experiment, you are free to do so at any time.

- **POTENTIAL BENEFITS**

You will have a chance to participate in research that will increase knowledge of human behavior and response to different alarms in Collision Avoidances Warning Systems. In the future this data may contribute to affecting designs of these systems, and be used to improve vehicle and roadway safety.

- **PAYMENT FOR PARTICIPATION**

Participation in this study is strictly on a volunteer basis and no compensation other than the gratitude of the investigators and possibly free snacks and drinks will be provided.

- **CONFIDENTIALITY**

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. You will be assigned a subject number that will be used on all related documents to include databases, summaries of results, etc. Only one master list of subject names and numbers will exist that will remain only in the custody of Professor Cummings.

- **IDENTIFICATION OF INVESTIGATORS**

If you have any questions or concerns about the research, please feel free to contact Angela Ho (617-452-4785) or Dr. Mary Cummings (617-252-1512).

- **EMERGENCY CARE AND COMPENSATION FOR INJURY**

In the unlikely event of physical injury resulting from participation in this research you may receive medical treatment from the M.I.T. Medical Department, including emergency treatment and follow-up care as needed. Your insurance carrier may be billed for the cost of such treatment. M.I.T. does not provide any other form of compensation for injury. Moreover, in either providing or making such medical care available it does not imply the injury is the fault of the investigator. Further information may be obtained by calling the MIT Insurance and Legal Affairs Office at 1-617-253-2822.

- **RIGHTS OF RESEARCH SUBJECTS**

You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you feel you have been treated unfairly, or you have questions regarding your rights as a research subject, you may contact the Chairman of the Committee on the Use of Humans as Experimental Subjects, M.I.T., Room E32-335, 77 Massachusetts Ave, Cambridge, MA 02139, phone 1-617-253-6787.

SIGNATURE OF RESEARCH SUBJECT OR LEGAL REPRESENTATIVE

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

____
Name of Subject

____
Name of Legal Representative (if applicable)

____	______________
Signature of Subject or Legal Representative	Date

SIGNATURE OF INVESTIGATOR

In my judgment the subject is voluntarily and knowingly giving informed consent and possesses the legal capacity to give informed consent to participate in this research study.

____	______________
Signature of Investigator	Date

APPENDIX B: PRE-SURVEY

Subject Code Name____________
Subject Code # ____________
Date ____________
Time ____________

Pre Simulation Questionnaire

Please fill in blanks or circle the one best response unless otherwise noted.

Your answers to these questions will be held confidential.

1. How old are you? _______________

2. Are you: male female

3. What is your occupation? If a student, list your major.

   ____

4. How many years have you been a driver? _____ years _____months

5. How many years have you had a driver's license? _____ years _____months

6. Do you have a:

   a. US License. Which State? _________________
   b. Other Country License. Which Country? _________________
   c. International License.

7. When was the last time you drove? _________ hours / days / weeks/ months/ years ago

8. In the **last year**, how often did you drive? Each 'time' is defined by each trip you make on a car.

   a. 5 days a week or more
   b. 3 - 4 days a week
   c. a few times each month
   d. Less than 10 times a year
   e. Less than 5 times a year
   f. None

9. In the **last year**, on a typical weekday, what is the **total distance** you drove?

Please answer considering a day which is typical for you, or approximate the average distance you would drive on a weekday.

_____ miles

10. In the **last year**, on a typical weekday, how much time did you spend driving?

Please answer considering a day which is typical for you, or approximate the average time you would spend driving on a weekday.

_____ hours   ______ minutes

11. On a scale of 1-10, how would you characterize your typical driving behavior?

1	2	3	4	5
Most Passive				*Most Aggressive*

12. When you drive, do you have difficulty keeping to your own lane?   Yes   no

13. If you answered "yes" to question 12, please further explain when does that happen, and why?

____

____

____

14. Please answer these questions about your experience in the **last year** and over your **lifetime**.

While driving, how many **times** have you:

	Last Year	Lifetime	Give examples of instances
Been in a collision where you had a frontal collision with another vehicle/ person/ building/ animal/ object?			
Been in a collision where you had a rear collision with another vehicle?			
Drifted out of your own lane, and thus suffered a collision with another vehicle/ person/ building/ animal/ object?			

15. Do you feel drowsy right now?   Yes   no

16. In which, if any, of the following do you usually get motion sick? (circle all that apply)

- Playing Video Games
- A train facing backwards
- A train facing forwards
- A bus
- The driver seat of a car
- The passenger seat of a car
- The back seat of a car
- An airplane
- On deck on a stationary boat
- On deck on a moving boats
- In the cabin of a stationary boat
- In the cabin of a moving boat
- Other please specify __________________
- None of the above

17. Do you take motion sickness medication, such as Dramamine, before traveling in? (circle all that apply)

- A train yes no
- A bus yes no
- The front seat of a car yes no
- The back seat of a car yes no
- An airplane yes no
- A boat yes no

18. How often do you play video games (PS, Xbox, Computer, Arcade, etc)

Thank you! Please let the Research Assistant know that you have completed the survey.

APPENDIX C: POST-SURVEY

Subject Code Name _____________
Subject Code # _____________
Date _____________
Time _____________

Post Simulation Questionnaire

Please fill in blanks or circle the one best response unless otherwise noted.

HEALTH

1. What kind of emotions did you feel while you were driving through the simulation scenarios?

	I do not feel this at all.					Describes exactly how I feel
Challenge	0	1	2	3	4	5
Fun	0	1	2	3	4	5
Enjoyment	0	1	2	3	4	5
Boredom	0	1	2	3	4	5
Stress	0	1	2	3	4	5
Frustration	0	1	2	3	4	5
Anxiety	0	1	2	3	4	5
Others:						
________________						

2. Do you feel unwell right now? Yes No (**If you answer No skip to question 5**)

3. If you answered "Yes" in question 1, how well does each of the following describe how you feel now? Please list any other symptoms in the additional spaces.

	I do not feel this at all.					Describes exactly how I feel
Nausea	0	1	2	3	4	5
Headache	0	1	2	3	4	5
Eye Strain	0	1	2	3	4	5
Drowsy	0	1	2	3	4	5
Dizzy	0	1	2	3	4	5

Please specify additional symptoms.						
____________	0	1	2	3	4	5

4. At which point during the experiment did you start to feel unwell and experienced the above-mentioned symptoms?

____

ALARMS

5. When your only task was driving, did you think that the alarms helped you in the following conditions by alerting you to them in time to…

    a. Avoid a Frontal collision Yes No
    b. Avoid a Rear Collision Yes No
    c. keep in your own lane Yes No

6. In what ways were the alarms helpful and/or not helpful in the above situations?

____

____

____

7. When you were distracted while driving, (having to do the additional "number-task"), did you think that the alarms helped you in the following conditions, by alerting you to them, in time to…

    a. Avoid a Frontal collision Yes No
    b. Avoid a Rear Collision Yes No
    c. keep in your own lane Yes No

8. In what ways were the alarms helpful and/or not helpful in the above situations while you were distracted?

____

____

____

9. When the alarms for the 3 conditions went off, did you know why it went off for:

    a. Frontal collision Yes No
    b. Rear Collision Yes No
    c. Drifting out of your own lane Yes No

10. If you answered "no" to question 9, why not?

____

____

11. If the alarms were not helpful to you, and/or if they also induced a negative emotive response, please elaborate on what these responses were, while you were driving under all circumstances (i.e. both non-distracted and distracted states):

Emotive Respon	In other words…	Frontal Collision Alarm	Rear Collision Alarm	Lane Drift Alarm
Ineffective & Neutral?	You saw the event before you the alarms, but the alarms didn affect you negatively.			
Annoying?	The alarms were not helpful, a wished that you could turn the			
Stressful?	In addition to the impending collision, you were stressed by alarms.			
Confusing?	You did not know what the ala meant and why they went off?			
Distracting?	In addition to being unhelpful, adversely affected your driving.			
Any other Reactions?				
____________				

12. What type of alarms do you think that you would have preferred for the following conditions?

a. Frontal collision Beeps / Voice alert. Example: _______/ Others:_______
b. Rear Collision Beeps / Voice alert. Example: _______/ Others:_______
c. Drifting out of lane Beeps / Voice alert. Example: _______/ Others:_______

TRAINING SCENARIOS + TESTING SCENARIOS

13. Did you think that you had enough training and practice time on the following training scenarios before you went on to the real testing scenarios?

a. 1st training scenario: CITY Yes No
b. 2nd training scenario: MOUNTAIN Yes No

If "no", why not?

____

14. Did you think that the length of the following scenarios was:

a.	1st training scenario	Too short	Too long	Just Right
b.	2nd training scenario	Too short	Too long	Just Right
c.	1st testing scenario	Too short	Too long	Just Right
d.	2nd testing scenario	Too short	Too long	Just Right

15. Were you able to predict when the events were going to happen in both the testing scenarios? If "yes", when?

a.	Frontal collision	Yes	No	____________________
b.	Rear Collision	Yes	No	____________________
c.	Drifting out of your own lane	Yes	No	____________________

16. What did you think about the simulated 'wind conditions'? Did they affect your driving and responses? Do you think that you difficulty keeping in your own lane during the windy periods?

____

____

____

____

17. What did you like/dislike about driving the different scenarios?

____

____

18. Did doing the number task while driving made it any harder to maintain safe driving?

Yes No

Why or why not?

____

____

19. Did you find the number task challenging enough to perform, while maintaining safe driving at the same time?

Yes No

If "no", would you have liked a more challenging task?

____

OVERALL EXPERIMENT AND SURVEYS

20. ` Do you have any comments / constructive criticisms / ideas/ suggestions for improvements on the:

a. First training scenario: City Streets?

____

____

b. Second training scenario: Mountain Roads?

____

____

c. Testing Scenarios 1 & 2?

____

____

d. How the experiment was conducted?

____

____

e. This survey in terms of format, clarity and succinctness of questions asked, and length?

____

____

f. If you found that the questions asked in this survey is redundant, please elaborate.

____

____

g. Any other comments / constructive criticisms / suggestions / rants?

____

____

Thank you for participating in this Pilot Study! Please do not discuss what happened during the experiment with anyone, as experiments are still ongoing.

APPENDIX D: FCWS TRIGGERING EVENTS

1. Oncoming vehicle on highway that overtakes another car, resulting in a head-on impending collision. The head-on oncoming car does not swerve back into its own lane.

Figure 9: At Top Of Hill, An Oncoming Car Appears

Figure 10: Oncoming Vehicle Imminent Collision

2. Moving vehicle on highway that brakes suddenly

Figure 11: Suddenly Braking Car

3. Stationary parked vehicle that pulls out from the side onto the driver's path.

Figure 12: Stationary Car Pulling Into Driver's Path

4. Stationary parked vehicle that backs out from a garage onto the driver's path, and then backs into the garage again.

Figure 13: Rows Of Parked Cars In Housing Estate

Figure 14: Car Backing Out & In of Garage

5. A tree fallen across the driver's lane and the driver is forced to swerve to avoid a collision. The tree appears at the top of a vertical curvature segment of the road, and so prevents the driver from seeing the object too early.

Figure 15: Tree Across Highway

APPENDIX E: RCWS TRIGGERING EVENTS

There is basically one type of RCWS triggering event which was a vehicle that quickly approaches the driver from the rear, with a closing velocity of 50 feet/second more than the speed of the driver. There were two ways by which the other vehicle could retreat at the last moment without crashing into the subject driver:

1. The moving rear vehicle surges up to the driver, and then backs off at the last moment when the 2 vehicles are within 2 feet of each other.

Figure 16: Rear Car Approaches Driver As Driver Reaches End Of Downhill

Figure 17: Rear Car Gets Closer To Driver

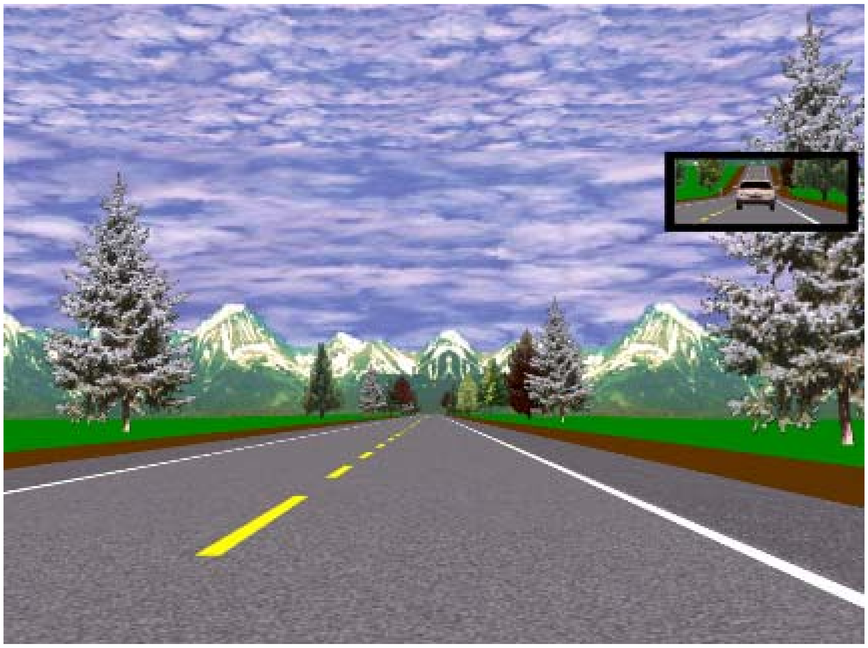

Figure 18: Rear Car Then Backs Away

2. The moving rear vehicle surges up to the driver, and then overtakes on the driver's left when the 2 vehicles are within 2 feet of each other.

Figure 19: Rear Car That Overtakes Driver On Left

Figure 20: Rear Car Speeds Off After Overtaking

APPENDIX F: TRAINING SCENARIOS

Pertinent scenes from the first urban training scenarios are as shown below:

Figure 21: Beginning Stretch Of Straight Road, With Wind Gusts

Figure 22: Entering Urban Streets With Traffic Lights

Figure 23: FCWS With Stationary Car Pulling Out From Side

Figure 24: Second Similar FCWS Event

Pertinent scenes from the second mountainous training scenarios are as shown below:

Figure 25: Slight curves

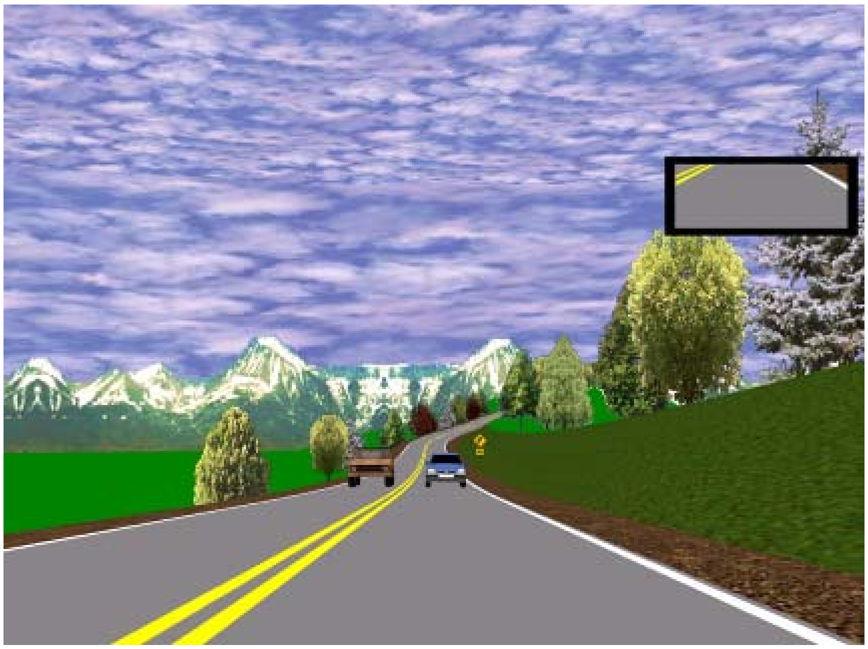

Figure 26: Oncoming Car

Figure 27: Rear Approach

Figure 28: Upward Hill With Limited Visual Cues

Figure 29: FCWS Event: Fallen Tree Across Road