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16. Abstract

We examined three characteristics of haptic cues from a vibrotactile seat interface (intensity, inter-pulse interval, and directional information), each at five levels, and a baseline/no-alert condition. One hundred eighty participants in good general health with no previous experience with a connected vehicle (CV) crash warning experienced a lateral collision event in an urban intersection with an intersection movement assist (IMA) CV warning. Each participant experienced only one haptic cue in the potential collision situation during one drive. Participants also completed a drive during which they subjectively evaluated all the haptic cues for category (notification, alert, or warning), the direction of threat (left, right, front, back, none), and an urgency rating (not urgent to very urgent). Drivers perceived the haptic cues with lower intensity (frequency) to be notifications, and higher intensities to be warnings. Vibration of the whole seat pan was perceived as more urgent than haptic cues that were presented in patterns where the vibration moved across the seat or cues were located on only one side of the seat. Vibration of the whole seat pan was not perceived as indicating a direction of threat. Drivers did perceive some haptic cue patterns to indicate different threat directions: vibrating only the left side of the seat indicated a threat to the left, vibration moving from front to rear on the seat indicated a threat to the front, and vibration moving from the right to left indicated a threat to the right. The driver's first response to the haptic cue were faster at 30 Hz depending on level of intensity, than other levels and intensity that may influence driver perception of haptic cues more than inter-pulse interval. Differences in driver classification of haptic cues as alerts or warnings, higher perceived urgency, or direction of threat did not translate into differences in the nature and speed of responses, nor the outcomes of the scenario.

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Executive Summary

The goal of this research is to determine haptic characteristics of a vehicle-to-vehicle (V2V) warning system interface that can be measured in an objective and repeatable way, the extent to which they contribute to the effectiveness of the safety system, and the amount of safety benefit they provide.

Alert characteristics for vibrotactile seat interface were examined. One hundred eighty (180) participants in good general health with no previous experience in a connected vehicle (CV) crash warning simulator study completed a practice drive, a study drive, and a drive during which they provided subjective evaluations of alerts. The study drive included an intersection movement assist (IMA) CV warning system that issued an alert to a lateral collision threat at an urban intersection. Independent variables were haptic cue intensity, inter-pulse interval, and directional information within the alert each at five levels, in addition to a baseline no-alert condition. Dependent measures included the outcome measure of collision, driving performance measures, and subjective measures of perception of the alert administered through a post-drive survey. The subjective alert evaluations from the final drive included the categorization of each alert (notification, alert, or warning), the direction of threat, and an urgency rating (not urgent to very urgent).

There were differences in drivers' perceptions of the haptic cues. Drivers classified lower intensity (frequency) cues to be notifications and, as the intensity increased, their classification of the cues moved to alert, then to warning. Similarly, vibration of the whole seat pan was perceived as more urgent than patterns where the vibration moved across the seat in a pattern or was located on only one side of the seat. However, drivers perceived different threat directions to be indicated by different haptic cue patterns. Vibrating only the left side of the seat indicated a threat to the left. Vibration moving from front to rear on the seat indicated a threat to the front, and vibration moving from the right to left indicated a threat to the right. However, no direction of threat was indicated by vibration of the whole seat pan. It seems that intensity is a more important factor in driver perception than inter-pulse interval. Differences in driver classification of haptic cues as alerts or warnings, higher perceived urgency, or direction of threat did not translate into differences in the nature and speed of responses, nor the outcomes of the scenario.

Chapter 1. Introduction

The safety benefit of crash warning (CW) systems is based on how well they address the target safety need and overall effectiveness of the system. For the purposes of this research, “safety benefit” is defined as the number of crashes prevented and amount of harm reduction, and Effectiveness is defined from the number of crashes with and without the particular characteristic that is being manipulated. Since the intention of these systems is ultimately to warn the driver with the goal of causing a correct and timely response, the warning itself is the limiting factor in the effectiveness and benefits of the system.

Where appropriate, NHTSA may define characteristics (e.g., frequency, intensity) of a CW driver vehicle interface (DVI) in a way that is intended to ensure safety without specifically dictating all elements of DVI design. To evaluate a DVI, manufacturers can use NHTSA-developed performance criteria and objective test procedures designed to evaluate system operation in engineering analysis, testing, or computer simulation.

1.1 Haptic Alerts

Haptic alerts have been studied to determine whether they can impart directional information leading to a shift of visual attention facilitating time-critical responses and their interaction with secondary tasks. Haptic alerts have been found to interfere less with secondary tasks, significantly reduce reaction time, and are the least central to driving (Meng & Spence, 2015; Spence & Ho, 2008; Scott & Gray, 2008; Hopstock et al., 2005). Additionally, multiple studies have found haptic alerts to be intuitive in demonstrating directional information (Ho et al., 2005; Hogema et al., 2009; Tan et al., 2003; Fitch et al., 2007). Participants in Hogema et al. could localize tactile cues presented through the seat pan with nearly perfect accuracy, with virtually all incorrect localization responses deviating by only one location segment (45°). Similarly, in Fitch et al., participants’ correct localization response jumped from 32 percent with an auditory alert to 84 percent with conditions involving a haptic alert, effectively reducing response time by 257 ms. Studies have also concluded several other beneficial effects of haptic warning systems. Participants in Brown etal. (2005) were 38 times more likely to stop at a red-light intersection approach than those receiving no warning, with multiple pulses (three 160 ms) having significantly higher peak and constant deceleration than other conditions. Baldwin et al. (2012) found haptic warnings to be well-suited to display a wide range of criticality levels. Additionally, haptic warnings appear to play a valuable role in driver notification and alerting in sensory-overloaded scenarios (Enriquez, 2001; Fels et al., 2006). Haptic warnings can improve brake response time)Scott & Gray, 2008), and potentially lead drivers to return their gaze and lift their foot from the pedal in a potential crash scenario quicker than with no warning (Fitch et al., 2007).

1.2 Representative Driving Scenarios

Intersections are widely recognized as one of the most hazardous driving scenarios. Rear-end, side-impact, and oncoming vehicle crashes are common at intersections and often caused by driver negligence and lack of information. In the United States, over 40 percent of all reported crashes occurred at or near an intersection (Tay, 2015). Based on this statistic, it is not surprising that intersections require drivers to put forth large amounts of cognitive effort to perceive and process information such as: traffic signs, intersection configurations, light patterns, and opposing vehicles. With all of this information to be processed, there is great potential for cognitive overloading. Researchers aim to reduce driver-related crash rates at intersections and lessen visual overload by implementing and improving upon current CW system technology.

This project focused on V2V safety applications in light vehicles appropriate for two-vehicle crash situations. Representative crash scenarios were identified through the Volpe National Transportation Systems Center's work, which was consulted on pre-crash scenarios and associated applications to identify specific scenarios for inclusion.

A report from Najm et al. (2013) reviewed national statistics for light-vehicle crashes. In it, 5 categories were developed pertaining to 10 priority V2V pre-crash scenarios: rear-end, lane change, opposite direction, left turn across path, and junction crossing (Figure 1). These 5 categories were chosen to be analyzed further, accounting for approximately 87 percent of the annual comprehensive economic cost and functional years lost for two-vehicle crash scenarios in light vehicles.

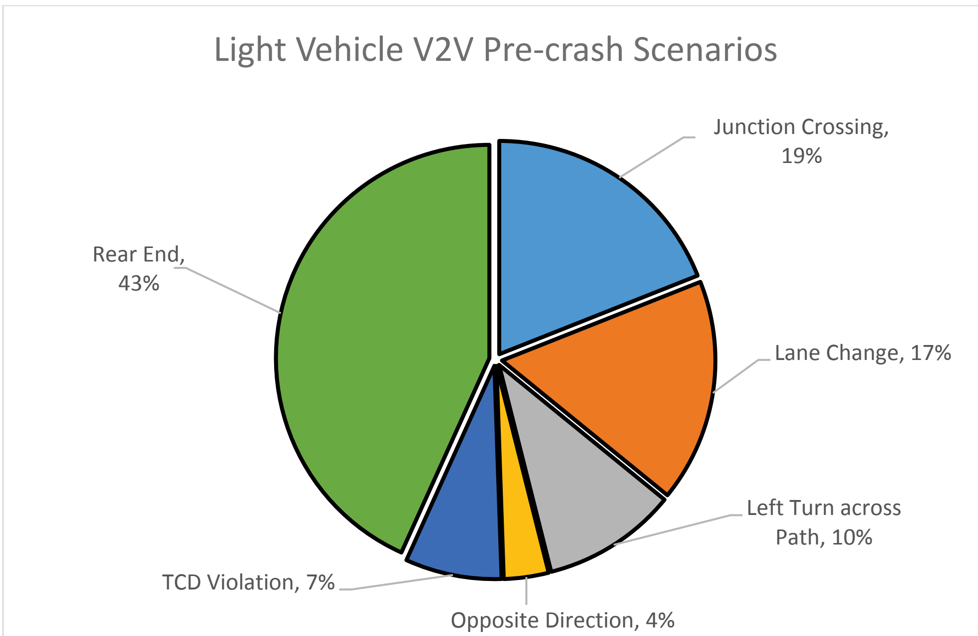

Figure 1. Percentage of Total Crashes by Pre-crash Scenario

The current study focuses on IMA with the implementation of a vibrotactile (haptic) seat. IMA systems warn the driver of a high probability collision with an incursion vehicle at an intersection, therefore junction crossing pre-crash scenarios were considered. A past report by Najm et al. (2011) identified straight crossing path at a non-signalized intersection to be the only relevant crash scenario for IMA warning systems. The most recent report by Najm et al. (2013) identified three additional crash scenarios out of the 17, for a total of four deemed appropriate for an IMA warning system.

- Left turn across path – opposite direction at non-signalized junctions
- Straight crossing path at non-signalized junctions
- Turning at non-signalized junctions
- Running a stop sign

One advantage of haptic alerts is their ability to convey directional information which, in the case of junction crossing crashes, is especially vital. Vehicular threats from an unambiguous lateral direction allow for a definitive evaluation of driver response to alert characteristics with few confounding factors, given the driver is not engaged in braking, steering, or acceleration maneuvers. This description fits straight crossing paths and running stop sign scenarios. Turning scenarios, in which the driver is steering and modulating speed at the beginning or end of a turn, create unwanted circumstances in which the driver's responses to the given alert are intermingled with the maneuver required, and therefore do not fit the ideal conditions.

IMA is a relatively new CW system showing promise, yet it lacks much literature. This study therefore aimed to expand upon that literature, examining vibrotactile seat alert characteristics in the event of a lateral collision threat at an urban intersection.

1.2.1 Lateral Collision Scenarios

The IMA system alerts the driver when there is a collision threat at an intersection. The intersection may be controlled or uncontrolled. IMA is best suited to warn the driver that another vehicle may violate an intersection control or of a collision threat at an uncontrolled intersection. Three potential scenarios are:

- Cross-traffic vehicle running a red light,
- Cross-traffic running a stop sign, and
- Cross-traffic at an uncontrolled intersection.

Running-red-light scenarios typically occur in urban areas with posted speed limits of 35 mph. Running-stop-sign scenarios typically happen in rural areas, also at aposted speed limits of 35 mph (Najm et al., 2007). Uncontrolled intersections often occur in urban areas with low posted speed limits, such as 25 mph, and in rural areas where the posted speed limits are 55 or 60 mph. For this study an urban environment with a posted speed limit of 35 mph at a traffic signal-controlled intersection was used as it represents a typical situation where lateral collisions occur.

1.3 Research Questions

Stimulus characteristics of a haptic warning are key components to CW interfaces and can be expected to affect the system's effectiveness and drivers' acceptance of the CW system. The research goal of this study was to determine haptic characteristics of a V2V warning system interface that can be measured in an objective and repeatable way, the extent to which they contribute to the effectiveness of the safety system, and the amount of safety benefit they provide. The hypotheses tested in this experiment were:

- Driver response will vary with different levels of haptic warning characteristic,
- Event outcomes will vary with different levels of haptic warning characteristic, and
- Driver perceptions of the warning will vary with level of haptic warning characteristic.

Chapter 2. Apparatus

2.1 NADS-1 Driving Simulator

Data collection was performed on the NADS-1 driving simulator. The NADS-1 simulator consists of a 24-foot-diameter dome (Figure 2) that encloses a full-size sedan and provides the highest level of driving realism and driver safety possible. The 13-degree-of-freedom motion system provides drivers with accurate acceleration, braking, and steering cues as if they were driving. The NADS-1 uses 16 high-definition (1920x1200) LED projectors to display seamless imagery on the interior walls of the dome with a 360-degree horizontal, 40-degree vertical field-of-view. The simulator cab is a 2015 Toyota Camry (Figure 3) equipped with active feedback on steering and the brake and a fully operational dashboard and infotainment display. Data from the simulator is sampled at 240 Hz.

Figure 2. NADS-1 Driving Simulator – Exterior

Figure 3. NADS-1 Driving Simulator – Interior

2.2 Driving Scenarios

Participants completed three drives in the simulator: a practice drive, a drive with the IMA event, and a drive during which they provided their subjective evaluation of the haptic cues. The environmental conditions in all three drives were daytime, clear weather, and a dry roadway in an urban setting with a posted speed limit of 35 mph.

2.2.1 Practice Drive

All participants began with a practice drive that allowed them to get used to steering, accelerating, braking, and maintaining lane position in the simulator (Figure 4). The practice drive started with the vehicle parked in the right-hand lane on a four-lane rural road with light ambient traffic in the oncoming lane. Through an automated voice prompt, the participant was instructed to shift the transmission into drive and begin driving. During the practice drive, traffic was present in the same direction of travel as the participant at sufficient distances to not interfere with participant's speed regulation of their own vehicle. The drive ended once participant had come to a complete stop at an intersection with a stop sign. This practice drive lasted approximately 8 minutes.

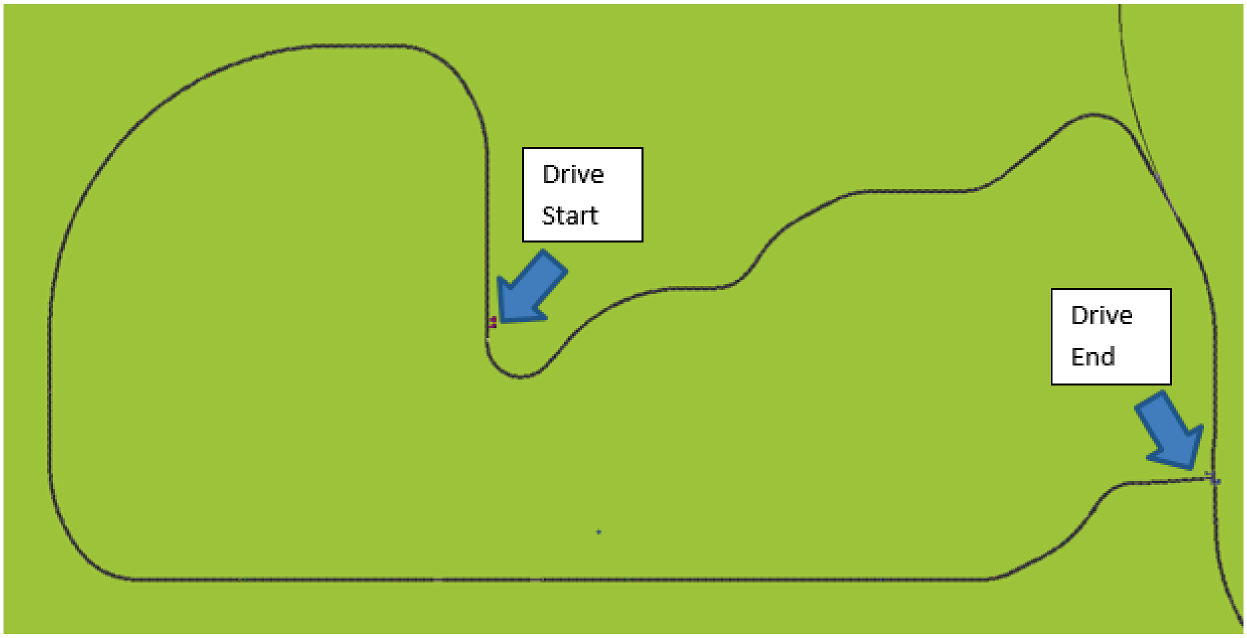

Figure 4. Practice Drive Map

2.2.2 IMA Drive

Driving on an urban street, the driver approached three traffic-signal-controlled intersections. There was light ambient traffic in the oncoming lane and the posted speed limit was 35 mph. At the two intersections prior to the event intersection, traffic crossed in front of the driver with a green or yellow light in the direction of the cross-traffic. All traffic signals cycled to green as the driver approached the intersection.

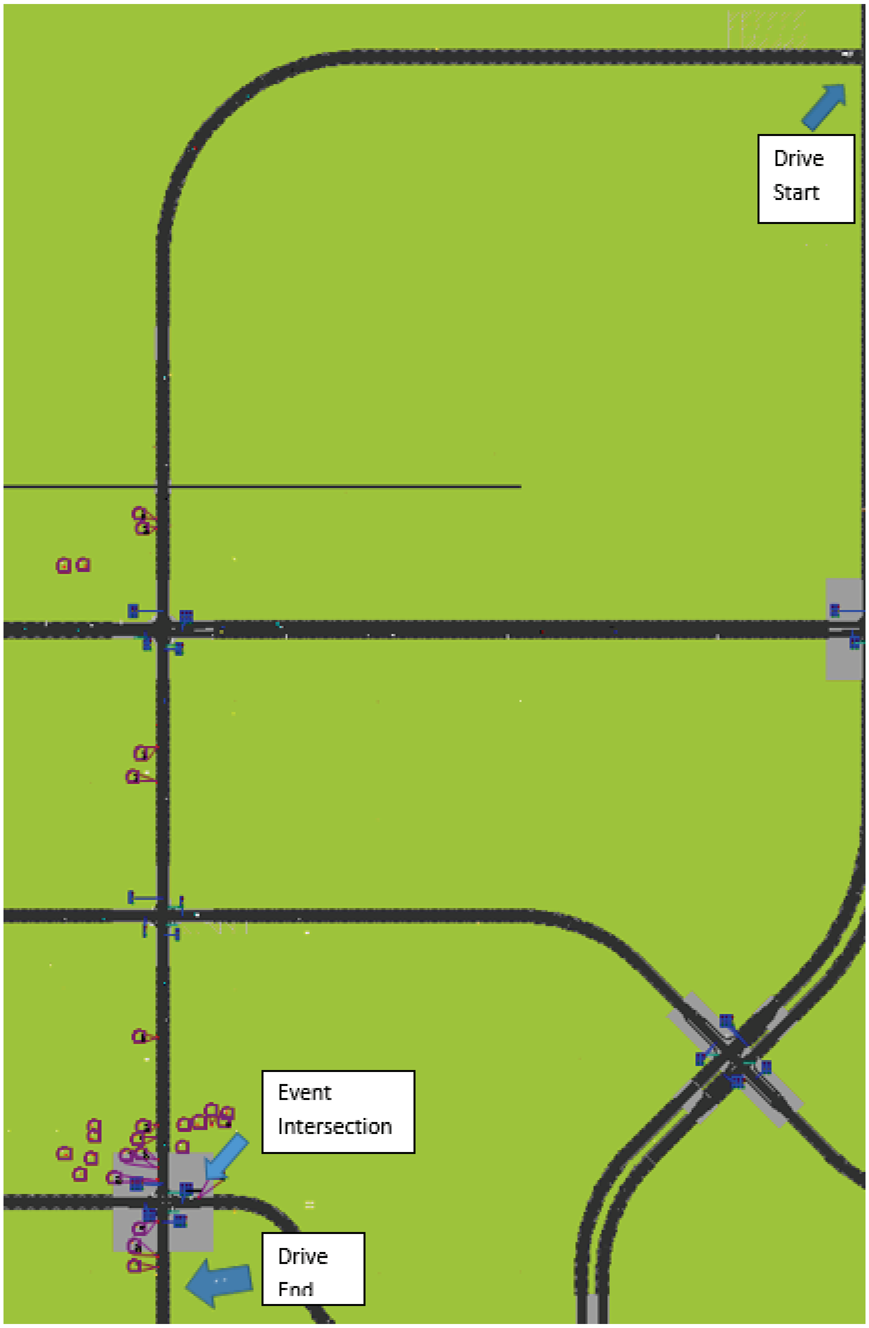

Figure 5. IMA Drive Map

As the driver approached the event intersection, the incursion vehicle was created as cross-traffic from the left at the driver's speed and at a sufficient distance from the collision point to accommodate event timing (Figure 6). The incursion vehicle approach was hidden by large parked vehicles to the left of the intersection. The scenario ended with a prompt after the driver reacted to the incursion vehicle and continued through the intersection. Figure 7 provides a visualization of the driving scene at the point of the IMA warning and Figure 8 provides a visualization of the driving scene at the point the incursion vehicle is first visible.

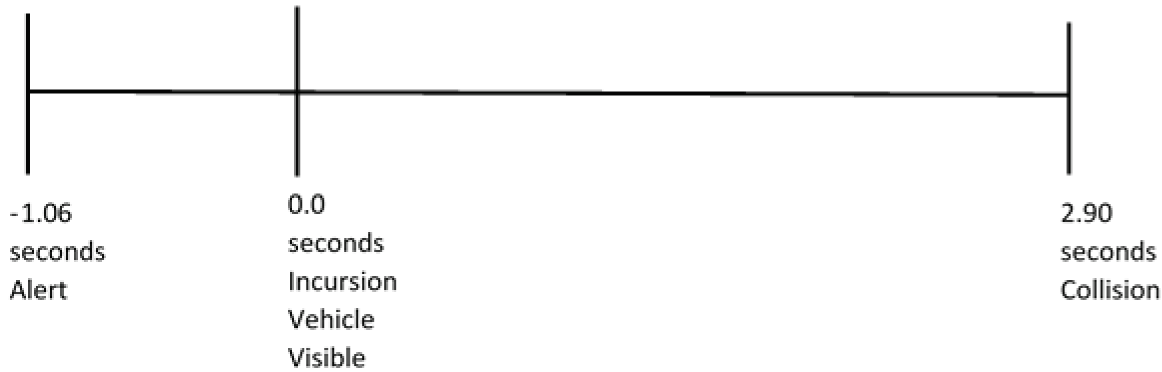

Figure 6. Timing of Intersection Collision Event With IMA System

Figure 7. IMA Event at Warning

Figure 8. IMA Event at Incursion Vehicle Visible

The time-to-visible of the incursion vehicle during the IMA event had a variation of approximately 0.15 seconds. This can be accounted for in two ways. First, because drivers had the freedom to drive as they naturally would, their lane position may have varied within the 12-foot wide lane. Small variations in lateral lane position could have created small changes in the angle and time at which the incursion vehicle was visible. The second reason is through the way the scenario was written. At 4 seconds to collision, the alert was triggered. At 3.1 seconds to collision, the incursion vehicle was created at the driver's speed. One-tenth of a second later, at 3 seconds to collision (approximately at the same moment as it became visible), the incursion vehicle speed was set to stay the same. If the driver's speed changed in that tenth of a second, the time to visibility changed as well.

2.2.3 Subjective Evaluation of Stimuli Drive

The third drive presented all 13 haptic cues in a random order between intersections to avoid association of the cues with the collision event in previous drive that may have skewed perceptions of some cues as more urgent. The haptic cues were presented within a driving context and without the presence of a threat since the goal was for drivers to provide either subjective perception of the cue rather than to elicit a threat avoidance response.

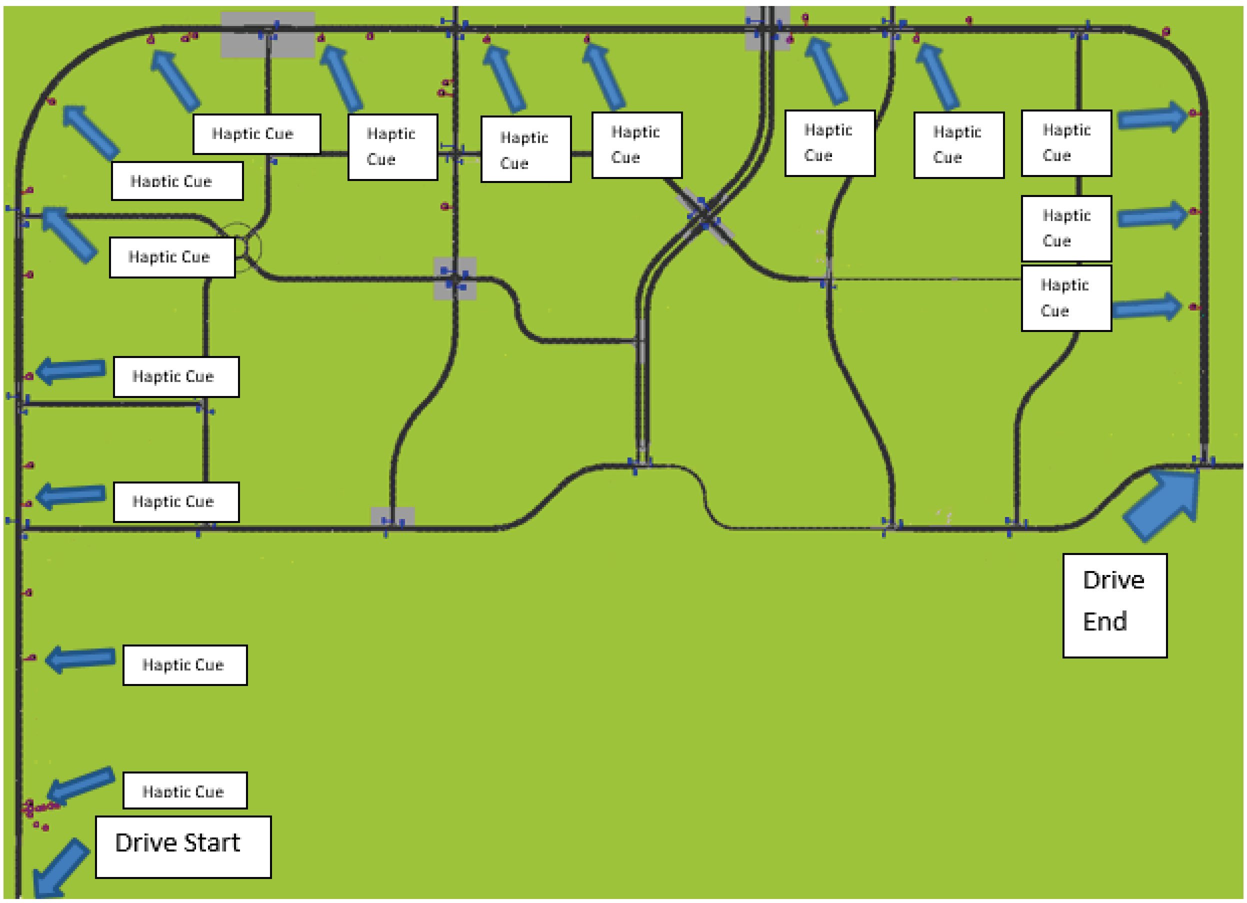

Figure 9. Subjective Evaluation Drive Map

After each cue, three questions were displayed on the infotainment center (Figure 10), and participants touched their responses on the screen for each. The questions included indicating the category of the haptic cue (Figure 11), indicating the direction the threat came from (Figure 12), and indicating the urgency of the haptic cue (Figure 13). Specific definitions were not provided to drivers for the notification, alert, or warning categories. The goal was to understand how drivers would naturally categorize the cues. Once all had been displayed and answered, the screen went blank until the next haptic cue was presented. If the participant did not respond to a question before the next haptic cue, the question disappeared prior to presentation of the next cue. The presentation order of the haptic cues was randomized across subjects. For each subject, a random order was generated of the 13 haptic cues. The entropy of the CPU was used as the seed for the random order generation. The randomness of the lists was verified using MATLAB's runs test function.

Figure 10. Display Location

Figure 11. Categorization Prompt

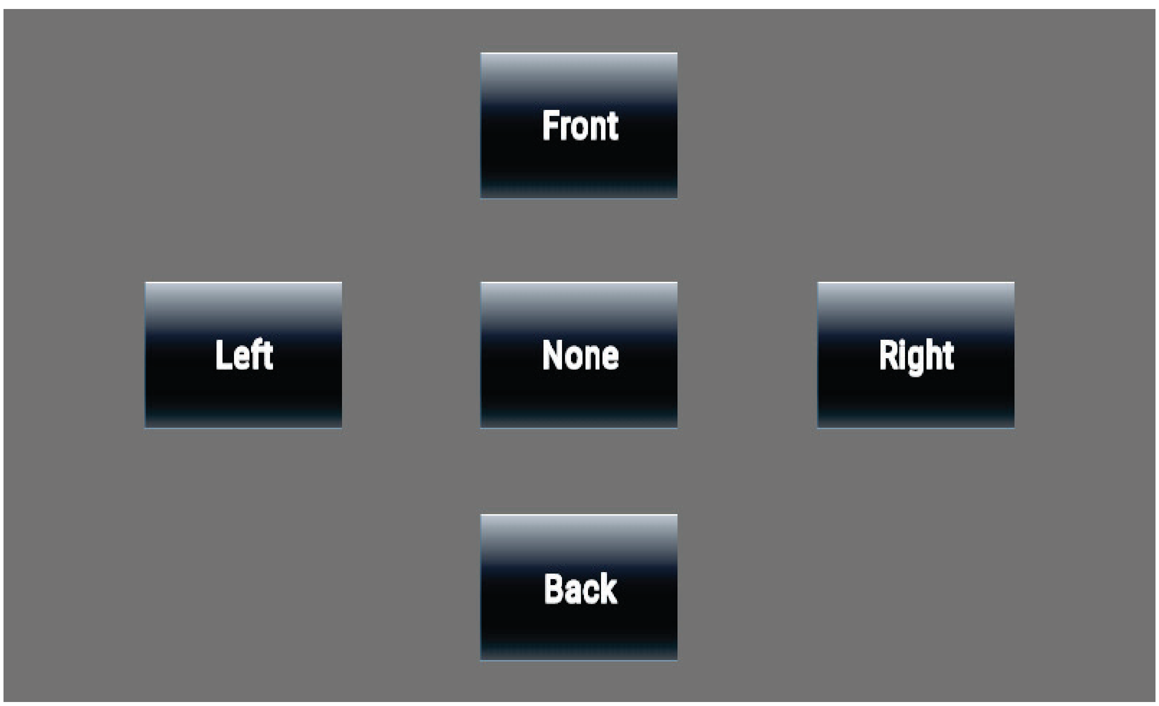

Figure 12. Direction of Threat Prompt

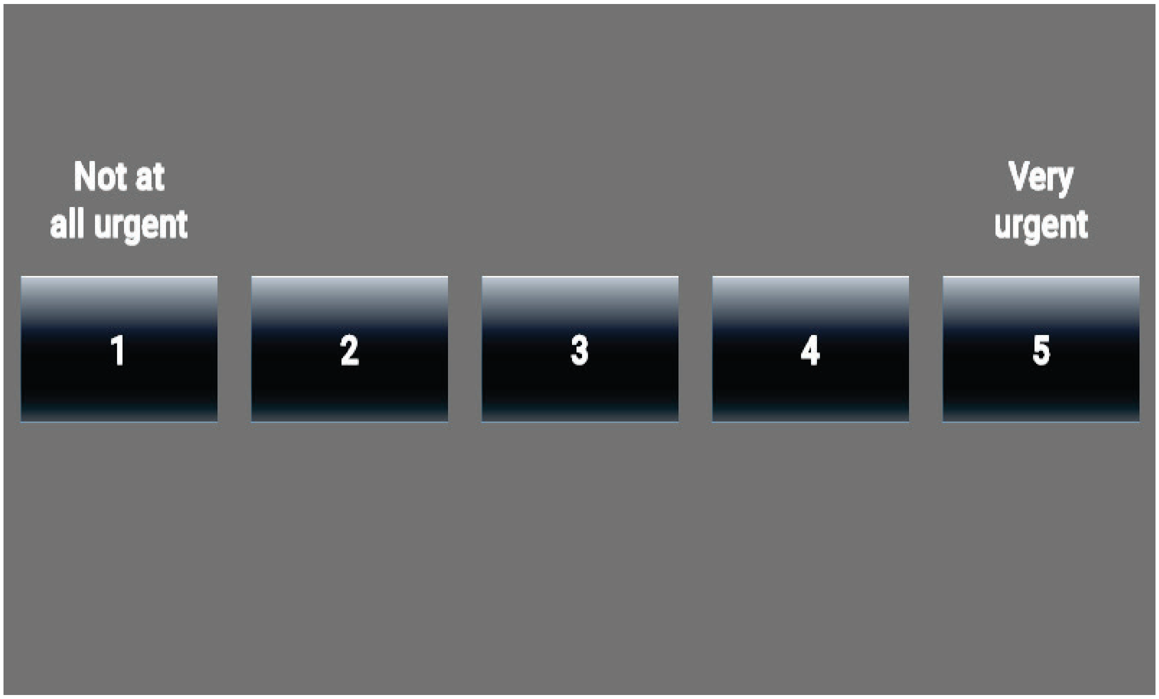

Figure 13. Urgency Rating Prompt

Chapter 3. Haptic Seat

The NADS-1 simulator is outfitted with a cab built from a 2015 Toyota Camry. The original driver's seat was replaced with a custom haptic seat that can be controlled through the scenario to support experimental needs (Figure 14). The actuators used in the custom seat are called "tactors" and were arranged in a 4x4 array providing more options for directional warnings. TAction Creator software and 16 C-2HDLF tactors and a 16-channel tactor controller in a single enclosure from Engineering Acoustics, Inc., were used to facilitate development of haptic actions. The tactors were tested individually, sequentially, and collectively on-the-bench. The upholstery was removed from the replacement seat. A layout template was drawn and used to mark the centers of each tactor's placement. The tactors were installed in the seat pan foam and their wire leads routed down through the foam to the underside of the seat where the controller was located (Figure 15). The seat was reupholstered to match existing upholstery in the simulator cab. The scenario for the study incorporated triggers to fire the haptic cue based on the driving situation. Vibration measurements of the tactors were taken periodically throughout this study to verify consistent haptic cues to all participants.

Figure 14. NADS-1 Cab and Seat

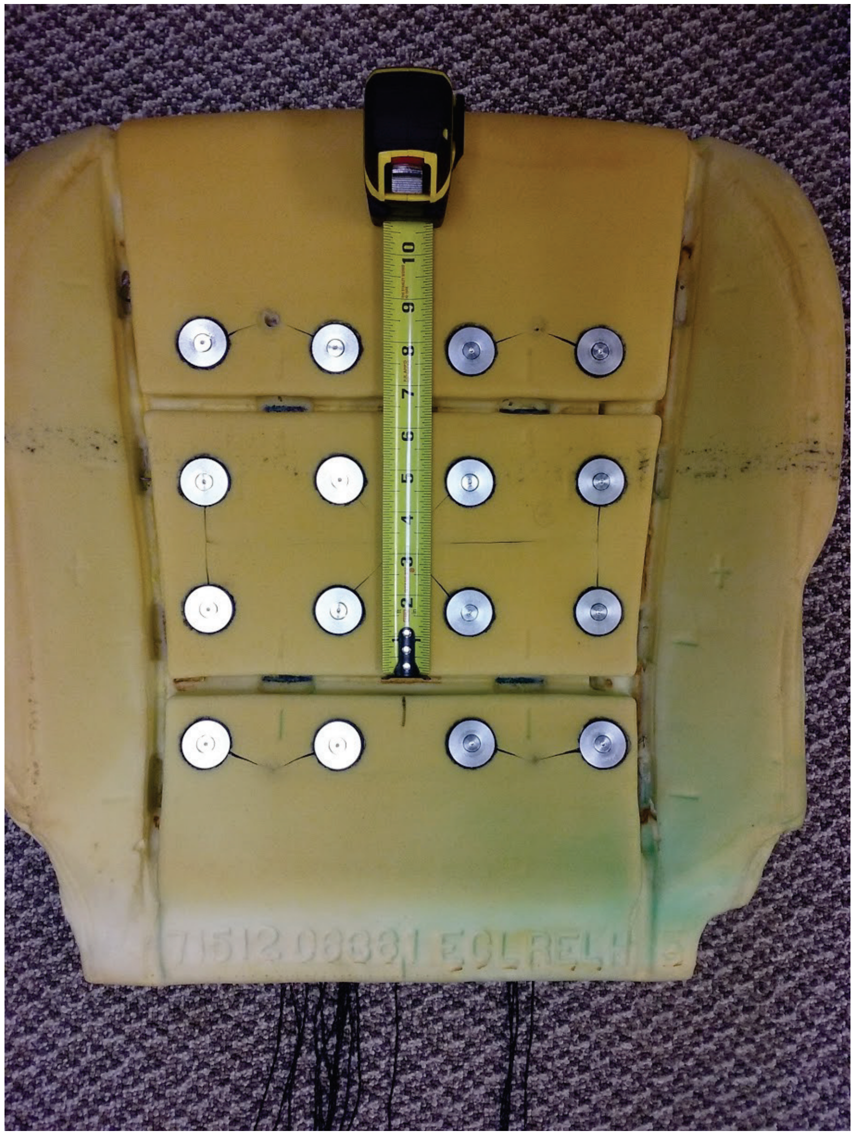

Figure 15. Haptic Seat Tactor Placement

Chapter 4. Methodology

This section describes the experimental design, independent and dependent variables, experimental protocol, and data verification and reduction procedures.

4.1 Pilot Testing

Pilot testing occurred in two phases. First pilot data for the intensity levels, then the inter-pulse interval and the directional pattern cues, were collected. Note that intensity refers to the frequency of the seat vibration. A half-cycle waveform was used. Inter-pulse interval is the time between pulses of vibration and is used to determine the determine the ratio between on and off states within a cue. The results of the intensity level pilot informed the later pilots.

Our original experimental plan was to analyze each characteristic as a separate study that included a baseline condition. In effect that meant that each row of Table 1 below would be a separate analysis. Note that the cells shaded in grey are repeated experimental conditions.

Table 1. Haptic Alert Characteristic Levels – Original Plan

Characteristic	Alert Level 1	Alert Level 2	Alert Level 3	Alert Level 4	Alert Level 5	Baseline
Intensity	30 Hz	40 Hz	50 Hz	60 Hz	70 Hz	no alert
Constant: Inter-Pulse Interval & Directional Pattern	0 ms Left only	0 ms Left only	0 ms Left only	0 ms Left only	0 ms Left only	
# of participants	10	10	10	10	10	10
Inter-pulse interval	0 ms	25 ms	50 ms	75 ms	100 ms	no alert
Constant: Intensity & Directional Pattern	70 Hz Left only	70 Hz Left only	70 Hz Left only	70 Hz Left only	70 Hz Left only	
# of participants	10	10	10	10	10	10
Directional pattern	Left only	Front-to-rear	Right-to-left	Left-to-right	Whole seat pan	no alert
Constant: Intensity & Inter-pulse Interval	0 ms 70 Hz	0 ms 70 Hz	0 ms 70 Hz	0 ms 70 Hz	0 ms 70 Hz	
# of participants	10	10	10	10	10	10

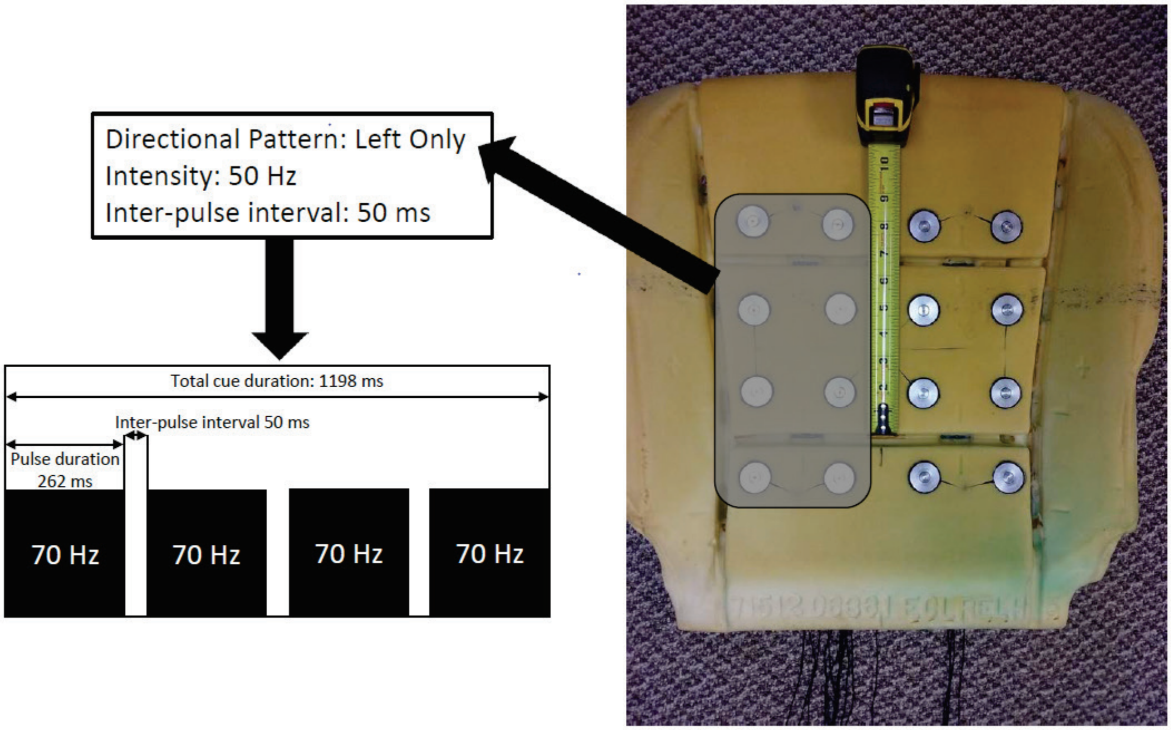

Figure 16. Visualization of Haptic Cue

While preparing for the pilot, an alternative plan arose. Intensity and inter-pulse interval could be analyzed as continuous variables and included in the same analysis while directional pattern is a categorical variable and would be analyzed separately. By eliminating the repeated experimental conditions and implementing the experimental conditions in Table 2 we were able to increase the number of participants per cell to 12. The alternative plan with 14 experimental conditions was approved during a regularly scheduled conference call on Tuesday, October 3, 2017.

When considering the sample size for the baseline condition where no warning is provided, it should be noted that due to a higher proportion of subjects who fail to respond to these types of events absent the warning, an increase in the sample size for that baseline is warranted in order to provide a more stable estimate for continuous measures such as accelerator release and brake press reaction time.

Table 2. Haptic Alert Characteristic Levels – Revised Plan

Characteristic	Alert Level 1	Alert Level 2	Alert Level 3	Alert Level 4	Alert Level 5	Baseline
Intensity	30 Hz	40 Hz	50 Hz	60 Hz	70 Hz	no alert 24 participants
Constant: Inter-Pulse Interval & Directional Pattern	0 ms Left only	0 ms Left only	0 ms Left only	0 ms Left only	0 ms Left only	
# of participants	12	12	12	12	12	
Inter-Pulse Interval		20 ms	50 ms	75 ms	100 ms	
Constant: Intensity & Directional Pattern		70 Hz Left only	70 Hz Left only	70 Hz Left only	70 Hz Left only	
# of participants		12	12	12	12	
Directional Pattern		Front-to-rear	Right-to-left	Left-to-right	Whole seat pan	
Constant: Intensity & Inter-pulse Interval		70 Hz 0 ms	70 Hz 0 ms	70 Hz 0 ms	70 Hz 0 ms	
# of participants		12	12	12	12	

4.1.1 Pilot 1 – Intensity Level

The first phase of pilot participants experienced all five intensity levels (30 Hz to 70 Hz) and the baseline (no alert condition). Pilot data was collected for the intensity experimental conditions before the other conditions to inform the choice of intensity level to be held constant across the other experimental conditions. Pilot data for the intensity conditions was collected October 9 to 17, 2017.

Table 3. Pilot 1 Haptic Stimulus Specifications

Alert # (ID)	Intensity Level Frequency (Amplitude)	Inter-Pulse Interval	Directional Pattern	Total Alert Duration	Number Pilot Participants
INT1	30 Hz (100%)	0 ms	Left only	1,200 ms	4
INT2	40 Hz (100%)	0 ms	Left only	1,200 ms	4
INT3	50 Hz (100%)	0 ms	Left only	1,200 ms	4
INT4	60 Hz (100%)	0 ms	Left only	1,200 ms	4
INT5	70 Hz (100%)	0 ms	Left only	1,200 ms	4
Baseline	Baseline (no alert)	Baseline (no alert)	Baseline (no alert)	Baseline (no alert)	4

Results for Pilot 1 – Intensity Level

The intensity level pilot data, , showed the 50 Hz level to have the fastest brake pedal press response time. This measure was chosen because it is the most prevalent active collision avoidance response. Based on this data it was determined that the haptic cues in the inter-pulse interval conditions and the directional pattern conditions would be presented at 50 Hz rather than the originally planned 70 Hz.

Table 4 Intensity Pilot Brake Pedal Response Time

	Baseline	30 Hz	40 Hz	50 Hz	60 Hz	70 Hz
Mean	1.80	1.69	1.52	1.37	1.97	1.63
Minimum	1.42	1.03	1.13	0.95	1.33	1.08
Maximum	2.30	2.37	1.90	1.83	2.60	2.37

4.1.2 Pilot 2 Inter-Pulse Interval and Directional Pattern

The original experimental plan (Table 1) included the specification for inter-pulse interval. All values are in milliseconds (ms). A limitation in the tactor software was discovered. Three suggested alternative specifications created that could be implemented (Appendix B). These alternatives were presented to NHTSA during a visit to NADS on October 16 and 17, 2017, and discussed with Christian Jerome, research psychologist for NHTSA's Human Factors/Engineering Integration Division, by conference call during the same visit. During that visit, Eric Traube, general engineer, NHTSA's Human Factors/Engineering Integration Division, experienced all three alternative inter-pulse intervals while driving the NADS-1 simulator. It was determined that Suggestion C would be implemented. Pilot testing for the inter-pulse interval levels and directional patterns proceeded and focused on confirming haptic cue implementation and main data collection procedures were valid.

4.2 Independent Variables

The study has a between-subjects design with each participant experiencing one crash scenario. This prevented priming participants to have faster responses in repeated crash situations. The independent variables were haptic characteristic (intensity, inter-pulse interval, directional information, baseline/no alert) and alert level (Table 5). Cells that are shaded grey have the same alert characteristics and were collected only once, resulting in 13 alert conditions and one baseline condition. Intensity levels for the haptic cues were based on a study conducted at VTTI (personal communication).

Pilot testing was conducted to determine the intensity level to be held constant in the conditions where the inter-pulse interval and directional pattern were varied. The results of the intensity pilot tests are discussed above. Intensity of 50 Hz, inter-pulse interval of 0 ms, and left-only directional pattern were held constant in conditions where other conditions were varied. All haptic cues were a total of 1,200 ms long (+/- up to 20 ms). Age levels and gender were counterbalanced in each experimental block. This design results in 12 unique participants per cell in the alert conditions and 24 in the baseline/no alert condition, for a total of 180 participants.

Table 5. Participants per Experimental Condition

Characteristic	Alert Level 1	Alert Level 2	Alert Level 3	Alert Level 4	Alert Level 5	Baseline
Intensity	30 Hz	40 Hz	50 Hz	60 Hz	70 Hz	
Constant:						
Inter-Pulse Interval & Directional Pattern	0 ms Left only	0 ms Left only	0 ms Left only	0 ms Left only	0 ms Left only	
Average Age of Participants	41.9	39.1	40.5	41.2	38.0	
# of Participants	12	12	12	12	12	
Inter-Pulse Interval		30 ms	60 ms	90 ms	120 ms	
Constant:						no alert
Intensity & Directional Pattern		50 Hz Left only	50 Hz Left only	50 Hz Left only	50 Hz Left only	24 participants
Average Age of Participants		38.3	38.6	36.9	37.2	Average age 39.2
# of Participants		12	12	12	12	
Directional Pattern		Front-to-rear	Right-to-left	Left-to-right	Whole seat pan	
Constant:						
Intensity & Inter-Pulse Interval		50 Hz 0 ms	50 Hz 0 ms	50 Hz 0 ms	50 Hz 0 ms	
Average Age of Participants		40.5	38.6	38.5	39.4	
# of Participants		12	12	12	12	

As can be seen in Table 5, intensity was varied from 30 Hz to 70 Hz at intervals of 10 Hz, resulting in five levels. One or more pulses with associated inter-pulse intervals are combined to make up a burst for a cue. Cues can be composed of a single burst or multiple bursts, with inter-burst intervals separating each burst. To examine only inter-pulse interval, pulses were combined into a single burst that comprised the entire alert (Figure 17).

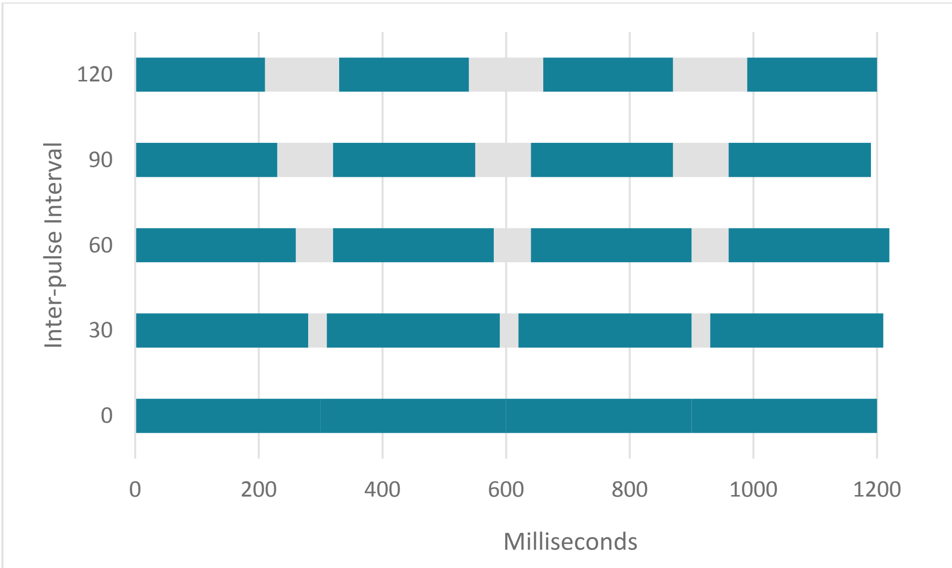

Figure 17. Haptic Cue Inter-Pulse Interval

Directional information was conveyed using five different tactor patterns to examine driver response to directional information that may be implied through vibrotactile seat alerts. The "Left Only" pattern used only the left two columns of tactors in the seat activated constantly for 1,200 ms. For the "Front-to-Rear" pattern the vibration started in the front row of tactors then moved one row at a time toward the back of the seat with each row activated for 300 ms. Similarly, the "Right-to-Left" and "Left-to-Right" patterns began in one column on the appropriate side and progressed through each column of tactors toward the opposite side of the seat with each column activated for 300 ms. The "Whole Seat Pan" pattern activated all tactors in the seat for 1,200 ms.

4.3 Dependent Measures

Dependent measures include three types of measures: outcome, driving performance measures, and subjective measures of perception of the alert administered through a post-drive survey. Measure definitions and subjective question stems are provided in Table 6. The outcome measure of collision is binary and indicates whether a collision occurred. All driving performance measures were calculated from the point where the incursion vehicle became visible to the participant. These measures provide insight into drivers' responses to the potential collision and include accelerator pedal release or press, brake pedal press, and steering. For the driver performance measures, negative values are responses after the alert and before the vehicle was visible to the driver. Positive values are responses after the incursion vehicle was visible. Accelerator pedal position is measured percentage displacement from 0 = not depressed to 1 = full depression. Brake pedal press response is indicated by force exerted on the brake pedal and is measured in pounds of force exerted on the pedal where 0 lb = no braking. The first response variable is included to capture all driver performance and includes all driver performance measures. The first active response variable excludes accelerator pedal release, yet includes accelerator pedal press, braking, and steering.

Table 6. Dependent Measures

Dependent Measure	Description
Outcome	
Collisions	Binary measure indicating whether the driver collided with incursion vehicle during scenario event
Driver Response	
Accelerator Release Time From Visible	Time to full accelerator pedal release, accelerator pedal position 0
Brake Response Time From Visible	Time to brake press as indicated by 3 pounds force (lb) on the brake pedal
Steering Response Time From Visible	Time to participant turning steering wheel 25 degrees or greater with a steering wheel velocity of 120 degrees per second during the response
Accelerator Press Time From Visible	Time to accelerator press of greater than 1 percent when max accelerator press is greater than 30 percent and max accelerator pedal velocity is greater than 2 percent per second.
First Response From Visible	Time to driver's first response whether it was accelerator pedal release, braking, steering, or accelerator pedal press
First Active Avoidance Response From Visible	Time to driver's first response whether it was accelerator pedal release, braking, steering, or accelerator pedal press
Post-drive Question Stems – Main Data Collection	
Did you know what sort of event the warning was trying to alert you to before you saw the other vehicle? - Selected Choice (yes/no)	
How easily and quickly could you interpret this warning? - Please rate using this 1-5 scale 1= very easily/quickly; 5 = very difficult/slowly	
How useful was the warning to you in this situation? - Please rate using this 1-5 scale 1 = very useful; 5 = not useful at all	
How distracting was this warning? - Please rate using this 1-5 scale 1 = not distracting at all; 5 = very distracting	
Subjective Evaluation Drive Only The questions were presented on the center console touchscreen and included perceived nature of the vibration, perceived direction of the threat, and perceived urgency of the vibration. Participants were instructed to respond with their "gut reaction" and not put too much thought into their responses.	
Perceived nature of the vibration Notification, Alert, Warning	
Perceived urgency of the vibration 1 = Not at all urgent, 5 = Very urgent	
Perceived direction of the threat None, Right, Front, Left, Rear	

4.4 Sampling and Participant Recruitment

Participants were recruited to meet age (25 to 55 years old) and gender requirements for a balanced sample. The sample was balanced for gender across all experimental conditions. For recruitment purposes only, the sample was split into two age groups (25-to-40 and 41-to-55 years old) to ensure a distribution of ages in all conditions and for both genders. Mean age for each age and gender group are shown in Table 7.

Table 7. Mean Participant Age and Gender

	Males	Females
All (25-55)	39.6	38.7
Young (25-40 years)	31.1	30.3
Middle (41-55 years)	48.1	47.0

For the pilot studies, 53 people were enrolled to reach 46 completed. Two were lost to simulator sickness, and the remaining 5 had issues with alert or event timing. For the main study, 212 participants were enrolled to obtain 180 completed. People were dropped due to:

- Being in the wrong lane at event,
- Excessive or slow speed at event (5 mph above or below the posted speed limit),
- Simulator issues, and
- Two subjects were dropped because they were run as alternates and their data was not needed.

Participants were compensated $40 for completing all study procedures. Two participants received $60 for returning to complete study visits due to simulator issues at their originally scheduled visit. Several inclusion and exclusion criteria were determined based on previous experiences conducting simulator studies. The inclusion criteria ensure participants meet age, licensure, driving experience, vision, hearing, and driving study experience requirements. The exclusion criteria ensure participants are free of health or medical conditions that may make driving in a simulator uncomfortable for them or cause their responses to differ from the normal driving population. Each participant met the following criteria.

- Inclusion criteria:
    - From 25 to 55 years old
    - Possess a valid U.S. driver's license
    - Licensed driver for 2 or more years
    - Restrictions on driver's license limited to corrective lenses
    - Drive at least 3,000 miles per year
    - Drive at least once per week
    - Report normal or corrected-to-normal vision
    - Report normal or corrected-to-normal hearing

- Does not use any special equipment to drive, such as pedal extensions, hand brake or throttle, spinner wheel knobs, or other non-standard equipment that would limit interpretation of accelerator pedal, brake pedal, or steering inputs
  - No participation in driving studies involving similar events or warning systems
  - Not identify as having a high likelihood of experiencing simulator sickness
  - Be in good general health and, if female, not pregnant
- Exclusion criteria:
  - Cancer (received any radiation and/or chemotherapy treatment within the last 6 months)
  - Crohn's disease
  - Parkinson's disease
  - Type 1 diabetes or uncontrolled Type II diabetes
  - Heart condition such as disturbance of the heart rhythm or a heart attack or a pacemaker implanted within the last 6 months
  - Suffered brain damage from a stroke, tumor, head injury, or infection
  - Stroke within the past 6 months
  - An active tumor
  - If diagnosed with seizures or epilepsy, a seizure in the past 12 months
  - Ménière's disease or any inner ear, dizziness, vertigo, hearing, or balance problems
  - Sleep disorder such as sleep apnea, narcolepsy, or chronic fatigue syndrome
  - Migraine or tension headaches requiring daily medication
  - Untreated depression, anxiety disorder, drug dependency, claustrophobia, or ADHD
  - Experienced any pain from neck or back injuries within the last year
  - Currently taking any prescription or over the counter medications with sedative side effects

4.5 Experimental Procedure

Potential participants were first screened by either online questionnaire or via telephone to determine if they qualified for the study (Appendix D and Appendix E). The online screening confirmed the inclusion criteria for driver license, driving experience, age, vision, and hearing. It also confirmed no exclusion criteria were met, such as serious health conditions, brain damage, seizures, balance or inner ear issues, sleep disorders, or neck or back injuries. A telephone screening was also used covering the same inclusion and exclusion criteria for potential participants who contacted the research team directly rather than through the online questionnaire. If the participant met all criteria and agreed to participate, the research team scheduled a study appointment time. Study appointment times were between 8 a.m. and 8 p.m. Monday through Saturday to ensure that data collection took place during participants' normal waking hours. If a potential participant worked nights, an appointment time was chosen during a time they would normally be awake.

Once the participant arrived at the study appointment, the experimenter verbally reviewed the Informed Consent Document (Appendix E), and then obtained participant's written consent. The informed consent document includes the purpose of the study, how many people will participate, how much time participation requires, overview of the study procedures, and a discussion of the risks involved in participating. All participants received a copy of the signed consent document at the end of their visit. Participants were asked to show their driver's licenses and the researcher confirmed validity. Participants filled out a payment form and video release form (Appendix F), and completed a questionnaire that covered some general questions about their age, gender, ethnic origin, vision, and age they first started to drive any type of vehicle (Appendix G).

Participants next viewed a PowerPoint training presentation (Appendix H). The presentation played on its own with narration for each slide. Participants were asked if they had any questions at the end of the presentation and any questions were answered by the researcher. The presentation included an overview of the NADS-1 simulator, including the type of vehicle they would be driving, the type of transmission, seat and steering wheel adjustment, fastening the seatbelt, and the resting position to assume between drives. The presentation also included a general description of the drives, that there would be three drives, how the drives would start, and any navigation instructions they would receive. Participants were instructed to drive as they normally would.

Participants were not told there would be a collision-imminent situation. This is consistent with the recommendations from the CWIM program (Lerner et al., 2015). Instead, they were told that the purpose of study was to examine differences in drivers across the United States. After participants viewed the training presentation, they were escorted to the simulator. Once seated in the simulator, participants were asked to adjust the seat and steering wheel to match their preferred driving position and for their comfort. A researcher rode with participants in the simulatorand sat in the back seat directly behind the participant to be as unobtrusive as possible. The researcher did not speak with the participant during drives other than to provide instructions or answer procedural questions. Following the practice drive and the study drive, the researcher administered questionnaires. Prior to the subjective evaluation drive, the researcher provided instructions to the participant for the response options that would be displayed on the infotainment center (Figure 10). During the drives, the researcher monitored the participant for signs of simulator sickness and could stop the drive if the participant was not feeling well. No participants were replaced for simulator sickness during the main study.

Participants first completed a 7- to 8-minute practice drive. Immediately following that drive, participants completed wellness questionnaires on which they reported any symptoms associated with simulator sickness (Appendix J). If reported symptoms were moderate or severe, their participation was ended for their comfort. Participants then completed the study drive, which lasted approximately 3 to 5 minutes. Immediately following the end of the study drive, participants were asked to complete another wellness questionnaire. Again, if they reported moderate or severe symptoms of simulator sickness, their participation was ended and they were replaced. After the second wellness questionnaire, participants were asked to fill out a short questionnaire about their perceptions of the alert. Finally, participants completed a subjective evaluation drive lasting approximately 10 minutes, which presented all the haptic cues in a random order. Participants were instructed to respond with their "gut reaction" and not over-think their responses. If necessary, after the subjective evaluation drive, participants received a follow-up wellness questionnaire. Participants were then read the debriefing statement that explained the true purpose of the research and any additional questions were answered before their study visit ended.

4.6 Data Verification

Following data collection each day, simulator data was backed-up onto NADS secure servers, where two copies existed to ensure against data loss. Verification and reduction of the simulator data took place throughout data collection to confirm valid data was collected for each participant. The first step in verification was to confirm the expected experimental conditions were run for each participant. This included age and gender as well as haptic cue characteristics. A review of the experimenters' notes from the study visit was used to identify any potential issues for individual participants, such as comments or delays in procedures that might have required additional review. A review of simulator data was used to confirm planned and actual experimental conditions matched.

Verification also included confirming the collision event unfolded as expected, including the timing and position of the incursion vehicle. The speed of the driver at the point the haptic cue was presented was reviewed to ensure similar event timing across participants. It was confirmed the driver was in the right-hand lane. Driver responses (accelerator pedal release/press, brake pedal press, steering) were also reviewed to ensure responses occurred following the haptic cue. Unexpected response patterns prompted a review of the drive video to confirm responses were appropriately captured. Outcomes were reviewed to ensure they were explained by driver responses. Collisions were reviewed to ensure post collision responses were excluded and instances of infinite time to collision were confirmed to be associated with a large steering response.

Issues with any data files were communicated to the principal investigator and data collection coordinator. Any issues in the data were discussed, investigated, and a course of action agreed upon for inclusion replacement of participants. Replacement participants were scheduled as quickly as possible so that they were distributed throughout the data collection periods as much as possible rather than pooled at the end. The data verification included frequent download and verification of data collected through online surveys to ensure a complete data set.

4.7 Data Reduction

After completion of data collection, data was reduced to summary measures and outliers were identified and removed. Data where no threat of collision existed (for example if the participant was traveling too fast or too slow) was identified and replaced. This occurred when speed at the time of alert was less than 30 mph or greater than 40 mph. Data from the post-drive survey was downloaded from the survey site and responses from participants replaced in the intersection crash event were dropped from the analysis. Data from the subjective evaluation drive were reduced to provide a single response for each question for each of the alerts resulting in 13 sets of subjective responses per participant. Subjective evaluation drive data was kept for all participants who successfully completed the drive, even if they were replaced from the intersection crash event.

Chapter 5. Data Analysis

The measures identified in Table 6 were analyzed to compare the levels of haptic characteristics. Analyses focused on the

- Subjective comparison of the alerts,
- Event outcome (collisions),
- Nature of response (steering, braking, accelerator press, no response),
- Speed of response (e.g., brake response time), and
- Perception of the alert.

5.1 Treatment of Outliers and Artifacts

The initial review of the simulator data during the analysis included box plots to visualize the distribution of the data. Extreme outliers were identified and reviewed for each measure. Outliers were investigated by reviewing the video and time-series data of the drive to determine the validity of the event. If the event triggered as planned, the data was retained for the analysis. Any outliers associated with mistimed events or other artifacts were excluded from the analysis. Note that data from all participants will be used for the subjective comparison analysis.

5.2 Analyses

Five analyses were conducted as part of this research:

- the nature of the response,
- the speed of the response,
- the outcome,
- the participant's perception of the alert received, and
- the subjective evaluation of all the alerts.

The following sections describe the approach for each of the analyses. Although gender was analyzed, it will only be reported if there was a significant interaction with the characteristic being analyzed.

5.2.1 Subjective Comparison of Alerts

Analysis of the data collected during the subjective evaluation drive included data from all participants who successfully completed the subjective evaluation drive, even if their data was excluded from other analyses. This data was analyzed by alert characteristic, resulting in three separate analyses. The response to each of the questions was analyzed using a chi-squared analysis for differences between the levels and where differences were found Mantel-Haenszel chi-squared for linear relationships. Data for significant differences is plotted using bubble plots.

5.2.2 Event Outcome

Analysis of the collisions that occurred during the vehicle incursion event at the end of the IMA drive (section 2.2.2, above) included data from all participants who successfully completed that drive. This data was analyzed by alert characteristic, resulting in three separate analyses. Baseline data was included as a level in each analysis to determine if the alert resulted in a difference in outcome compared to the baseline conditions. The distribution of alert characteristics versus outcome was analyzed using a chi-square analysis. When interactions between alert characteristic and gender are present, they will also be reported.

5.2.3 Nature of Response

This data was analyzed by alert characteristic resulting in three separate analyses. Baseline data was included as a level in each analysis. The distribution of alert characteristics versus initial response type were planned to be analyzed using a chi-square analysis. Due to small cell sizes, even collapsing responses did not produce expected values sufficient to meet requires for conduction a chi-square analysis. Response counts will be reported.

5.2.4 Speed of Response

The data was analyzed by alert characteristic, resulting in three separate analyses. The response times for each type of response and for first response were analyzed using SAS General Linear Model's (GLM) procedure. Included in the analyses as class variables were the independent variable of interest (intensity, inter-pulse interval, or directional pattern), gender, and participant. All interactions were included in the model. For statistically significant effects ($p<0.05$), a Tukey post-hoc test was performed to identify differences between levels, and a Dunnett's one-tailed t-test was performed to determine if the response was faster than baseline. Data is plotted, with the baseline data distribution overlaid on the graphs.

5.2.5 Perception of the Alert

The post-drive survey data was analyzed by alert characteristic, resulting in three separate analyses. The response to each of the questions was analyzed using a chi-square analysis for binary data and using SAS GLM procedure for data from Likert scale questions.

Chapter 6. Results

The results from this research are presented in five main analyses. The analyses are organized by haptic characteristic.

6.1 Intensity (Frequency)

Recall that all levels of intensity were presented using the 0 ms inter-pulse interval and the "Left" directional pattern.

6.1.1 Subjective Assessment

Differences were found between the intensity levels for driver classification ($\chi^2(8) = 272.2$, $p<0.0001$) and perceived urgency ($\chi^2(16) = 285.3$, $p<0.0001$) of the haptic cue and are shown in Figure 18 and Figure 19, respectively. There are also linear relationships for driver's classification ($\chi^2(1) = 43.7$, $p<0.0001$) and perceived urgency ($\chi^2(1) = 236.8$, $p<0.0001$) with haptic cue intensity. Lower intensities (frequencies) are perceived to be notifications and less urgent. As intensity of the haptic cue increased, drivers' classifications of the haptic cues move toward alert and then warnings. At the higher intensity levels, 60 Hz and 70 Hz, the cue was classified as a warning by the majority of participants as indicated by the pink shaded bubbles. Also, at the lower levels of intensity, 30 Hz, 40 Hz, and 50 Hz, the cue was rarely classified as a warning. The same increase is observed in perceived urgency. These patterns of classification and perceived urgency as intensity increases is consistent with the urgency mapping principle often applied to auditory alerts (Edworthy et al., 1991; Edworthy & Adams, 1996). It is also consistent with the findings of Baldwin et al., (2010). At all intensity levels the majority of drivers reported perceived direction of threat from the left (67.6% to 81.2%), which confirms that a vibration only on the left side of the seat is useful directional information ($\chi^2(16) = 21.8$, $p=0.1499$). The results for five directional patterns (section 6.4.1) also indicate directional information is conveyed.

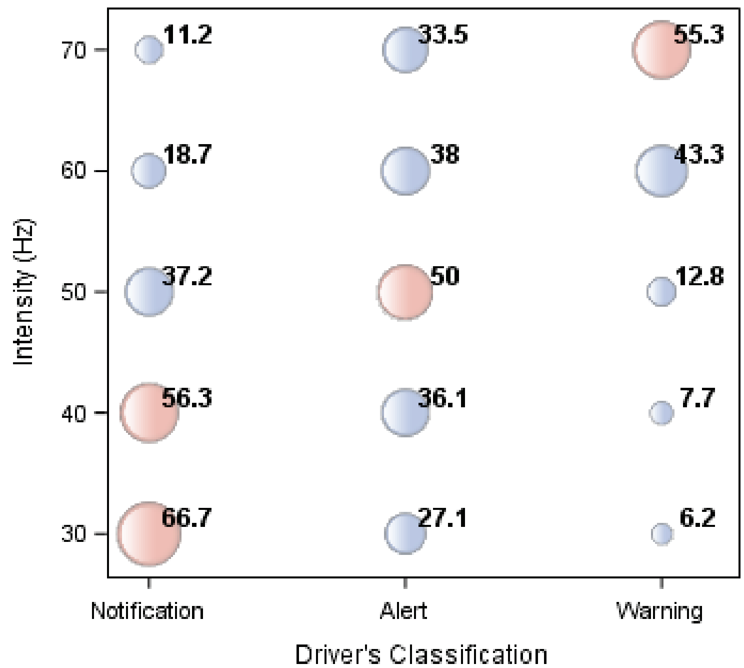

Figure 18. Driver's Classification for Intensity

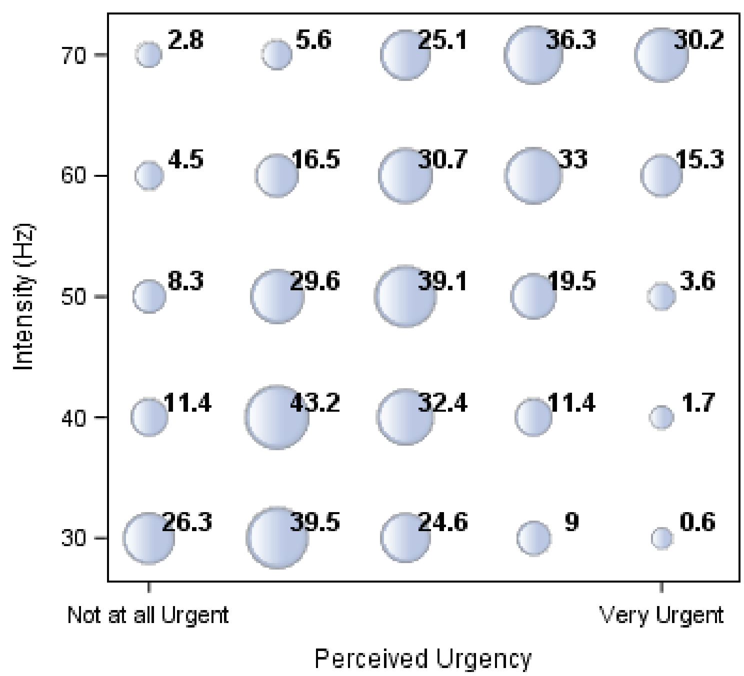

Figure 19. Perceived Urgency for Intensity

6.1.2 Outcome (Crashes)

Even though the higher intensity levels were perceived as warnings and to have greater urgency, they did not result in lower crash rates. No significant differences were found between intensity levels ($\chi^2(5) = 1.75$, $p=0.8820$). Recall that there were 12 participants in each alert condition and 24 participants in the baseline condition (Table 5). The counts shown in Table 8 reveal that, while there was some variation in number of crashes across conditions, there are no discernable differences or trends. The potential crash situation presented was severe and crashes were difficult to avoid without a quick and significant avoidance response from the driver. The nature and speed of response may reveal differences between intensity levels that are not evident in the crash count.

Table 8. Crashes by Intensity Level

Intensity	Baseline	30 Hz	40 Hz	50 Hz	60 Hz	70 Hz
# No Crash	11	7	5	5	4	6
# Crashes	13	5	7	7	8	6

6.1.3 Nature of Response

First Response

Recall that first response is the first action the driver takes following the warning system alert. First response can be releasing the accelerator pedal, pressing the accelerator pedal, pressing the brake pedal, or steering. It should be noted that the first response variable is predominantly release of the accelerator pedal, which is expected for an unanticipated collision event. Only responses following the issuance of the haptic cue are included. Where brake pedal press or steering responses are the first response, drivers had released the accelerator pedal prior to issuance of the haptic cue. Drivers' first responses at baseline and all levels of intensity are shown in Table 9. There were no significant differences in first response for intensity. As with the crash counts, there are no discernable differences or trends in the variation across the levels of intensity. The lack of braking and steering responses in the baseline/no alert condition confirms the event was unanticipated when an alert was not presented.

Table 9. First Response by Intensity Level

Response	Baseline	30 Hz	40 Hz	50 Hz	60 Hz	70 Hz
Accelerator Pedal Release	19	9	11	7	9	10
Accelerator Pedal Press	5	2	0	1	1	0
Brake	0	1	1	1	1	1
Steer	0	0	0	3	1	1

First Avoidance Response

By removing accelerator pedal release, the remaining responses are the drivers' active collision avoidance responses: pressing the accelerator pedal, braking, or steering. Table 10 shows the first avoidance response for baseline and all intensity levels. The response counts for this measure indicate the action drivers took after releasing the accelerator pedal, if they did so, and can be seen in the shift in the brake pedal press and steering response counts. The first active response may reveal differences in types of avoidance response. There were no significant differences in first avoidance response for intensity. Again, there are no clear trends across the levels of frequency. Most participants pressed the brake pedal as their first active response, though a few steered and fewer yet chose to press the accelerator pedal.

Table 10. First Avoidance Response by Intensity Level

Response	Baseline	30 Hz	40 Hz	50 Hz	60 Hz	70 Hz
Accelerator Pedal Press	5	2	0	1	1	0
Brake	16	10	9	6	6	8
Steer	3	0	3	5	5	4

6.1.4 Speed of Response

First Response

There was a significant effect of intensity on speed of first response ($F(5,72)=2.37, p<0.0479$). The 30 Hz level showed faster responses than the baseline and other intensity levels (Figure 20). That these results are different than might be expected based on the subjective classification of notification, alert, or warning and perceived urgency. For instance, it may be expected that cues classified as notifications would also have slower response times and cues classified as alerts or warnings would have faster response times. However, the results show a different pattern. The higher intensities were more often classified as warnings and rated with higher perceived urgency, yet only the lowest intensity level, 30 Hz, had a faster first response time than the baseline/no alert condition. The intensity levels of 40 Hz and 50 Hz had longer response times than the baseline and were classified as a notification (40 Hz) or an alert (50 Hz), which seems consistent, while the 60 Hz and 70 Hz levels had response times similar to baseline/no alert even though they were primarily classified as alerts or warnings and assigned higher perceived urgency.

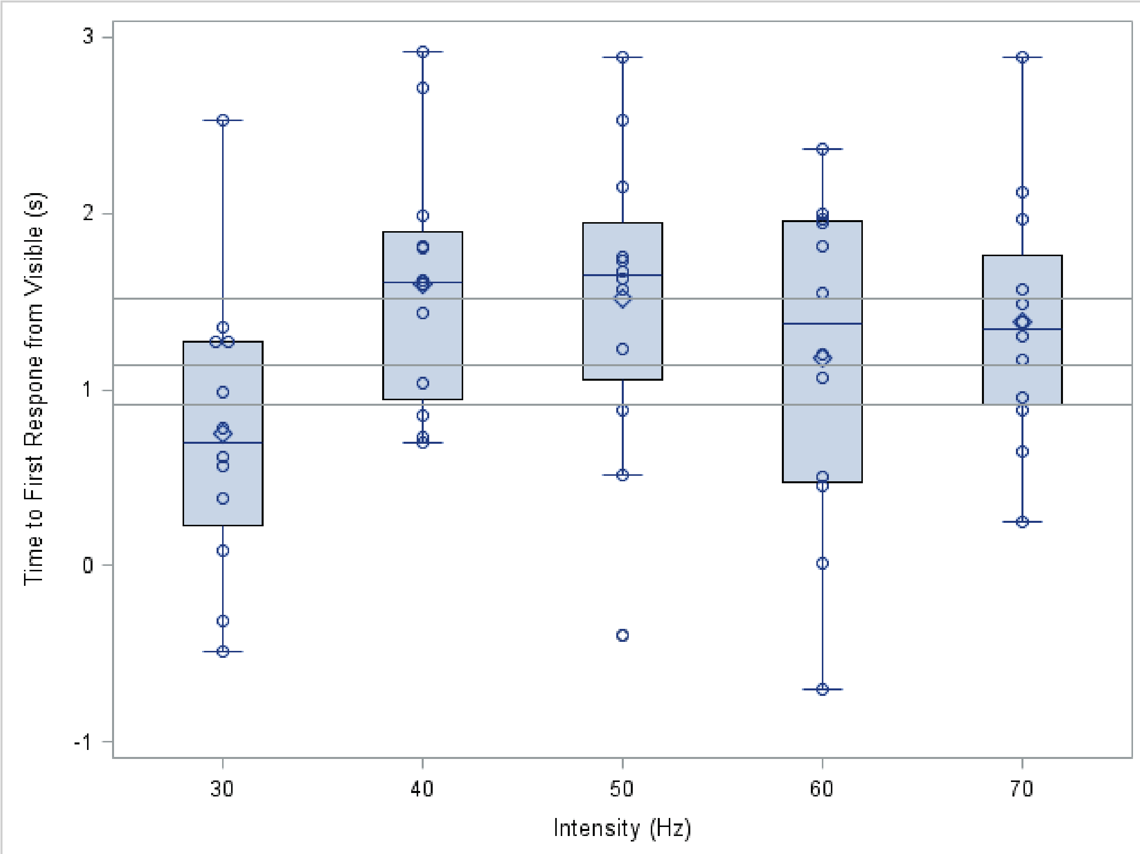

Figure 20. First Response Time for Intensity

First Avoidance Response

No statistically significant differences were found for intensity on speed of first avoidance response (F(5,67)= 1.00, p=0.4253). The lack of differences here compared to the difference seen for first response reveal the accelerator pedal release.

Individual Response Types

No statistically significant differences were found for level of intensity on accelerator pedal release response time (F(5,60)= 1.49, p=0.2070), brake pedal press response time (F(5,55)= 1.91, p=0.1073), or maximum deceleration (F(5,72)= 1.62, p=0.1645). Higher deceleration was seen at 70 Hz level and is consistent with the later brake pedal press also seen in this condition. No significant effect was found for intensity in steering response time (F(4,11)= 1.64, p=0.2322). No meaningful differences were found in accelerator pedal press by directional pattern due to the small number of responses (four).

6.1.5 Perception of the Alert

No significant effect was found for intensity in knowledge of the type of event ($\chi^2(4) = 5.70$, p=0.2224), ease of interpretation (F(4,39)=1.98, p=0.1171), usefulness of the warning or distractibility of the warning (F(4,34)=1.09, p=0.3768), or in distractibility of warning (F(4,36)=1.87, p=0.1376). Recall that only the left side of the seat was activated across the different levels of intensity; therefore, no differences in the knowledge of type of event is not surprising. The results for the directional patterns, discussed below, may provide more insight. No differences in the usefulness or distractability of the warning indicates that haptic cues neither gain nor lose usefulness or become more distracting across the intensity levels presented in this study.

6.2 Inter-Pulse Interval

Recall that, based on the pilot results, all inter-pulse interval levels were presented at 50 Hz using the "Left" directional pattern and this experimental condition was collected only once (Table 5). This means that the results for the 0 ms level are the same as those as the 50 Hz intensity level.

6.2.1 Subjective Assessment

No differences were found between levels of inter-pulse interval for the drivers' classification of the signal ($\chi^2(8) = 11.1$, p=0.1956), perceived direction of threat ($\chi^2(16) = 7.2$, p=0.9687), or perceived urgency ($\chi^2(16) = 20.0$, p=0.2187). Drivers classified the alerts to be either notifications or alerts rather than warnings. Recall that, based on pilot data, the 50 Hz intensity was used for all levels of inter-pulse interval and the percentages reported for the 50 Hz level (Figure 18) are similar to these for inter-pulse interval: 37.2 percent notification, 50 percent alert, 12.8 percent warning. Similarly, the reported perceived urgency closely resembles the 50 Hz. level (Figure 19): 8.3 percent not at all urgent, 29.6 percent, 39.1 percent, 19.5 percent, 3.6 percent very urgent. Again, the perceived direction of threat as "Left" confirms that a haptic signal from only the left side of the seat conveys effectively.

6.2.2 Outcome

No significant difference in outcome (crashes) was found for levels of inter-pulse interval ($\chi^2(5) = 0.80$, p=0.9769). The outcome was essentially the same between crash and no crash across all levels of inter-pulse interval and is quite similar to the 50 Hz level of intensity. It is possible that intensity has more influence on driver perception and response than inter-pulse interval. If this is true, then it would be expected that results for all levels of inter-pulse interval are similar to those for the 50 Hz intensity level.

Table 11. Crashes by Inter-Pulse Interval

Intensity	Baseline	0 ms	30 ms	60 ms	90 ms	120 ms
# No Crash	11	5	6	5	5	4
# Crashes	13	7	6	7	7	8

6.2.3 Nature of Response

First Response

Recall that first response is the first action the driver takes following the warning system alert and that only responses following the issuance of the haptic cue are included. No significant difference in first response was found for levels of inter-pulse interval ($\chi^2(5) = 2.88$, p=0.7191). As seen in the previous outcome, the pattern of responses is quite similar to the 50 Hz intensity condition across all levels of inter-pulse interval lending more support to the idea that intensity affects driver response more than inter-pulse interval.

Table 12. First Response by Inter-Pulse Interval

Response	Baseline	0 ms	30 ms	60 ms	90 ms	120 ms
Accelerator Pedal Release	19	7	7	8	9	9
Accelerator Pedal Press	5	1	3	1	1	1
Brake	0	1	2	3	2	2
Steer	0	3	0	0	0	0

First Avoidance Response

No significant difference in first avoidance response was found for levels of inter-pulse interval ($\chi^2(5) = 9.51$, p=0.0904). While the 60 ms inter-pulse interval resulted in a greater number of brake pedal press responses than other levels, those braking responses did not translate into fewer crashes (Table 11). It is most likely the magnitude of braking response at the time to collision the brake application occurred was not sufficient to avoid crashes.

Table 13. First Avoidance Response by Inter-Pulse Interval

Response	Baseline	0 ms	30 ms	60 ms	90 ms	120 ms
Accelerator Pedal Press	5	1	3	1	1	1
Brake	16	6	7	11	7	7
Steer	3	5	2	0	4	4

6.2.4 Speed of Response

First Response

No statistically significant differences were found for inter-pulse interval on speed of first response ($F(5,72)=2.21$, p=0.0626). Since all levels of inter-pulse interval were presented at the 50 Hz intensity level, this result provides more support for the idea that intensity influences driver response more than inter-pulse interval.

First Avoidance Response

No statistically significant differences were found for inter-pulse interval on speed of first avoidance response (F(5,78=1.90, p=0.1059). Again, the lack of significant differences supports the idea that intensity has more influence on driver response than inter-pulse interval.

Individual Response Types

No statistically significant effect was found for inter-pulse interval on accelerator pedal release ($F(5,54)=0.63$, p=0.6765), brake pedal press ($F(5,58)=1.24$, p=0.3035), maximum deceleration ($F(5,72)=0.49$, p=0.7795), or steering response (F(5,11)=3.04, p=0.0577). Even though there were several brake pedal press responses for the 60 ms level of inter-pulse interval (Table 13), the lack of significant differences here combined with the lack of differences in the number of crashes (Table 11) means the braking responses were similar across conditions and ineffective for crash avoidance. No meaningful differences were found in accelerator pedal press by inter-pulse interval due to the small number of responses (6).

6.3 Perception of the Alert

No significant effect was found for inter-pulse interval in knowledge of the type of event ($\chi^2(4) = 6.68$, p=0.1535), ease of interpretation ($F(4,35)=0.09$, p=0.9859), usefulness of the warning (F(4,35)=0.56, p=0.6936) or distractibility of the warning ($F(4,35)=0.69$, p=0.6041). Recall that only the left side of the seat was activated across the different levels of inter-pulse interval. As with intensity above, no differences in the knowledge of type of event is not surprising and the results for the directional patterns may provide more insight. Also, as with intensity, no differences in the usefulness or distractability of the warning indicates that haptic cues neither gain nor lose usefulness or become more distracting across the inter-pulse interval levels presented in this study.

6.4 Directional Pattern

Recall that, based on the pilot results, all directional patterns were presented at 50 Hz, with 0 ms inter-pulse interval, and this experimental condition was collected only once (Table 5). This means that the results for the "Left" directional pattern are the same as those as the 50 Hz intensity and 0 ms levels.

6.4.1 Subjective Assessment

Significant differences were found for drivers' classification of haptic cue ($\chi^2(8) = 108.5, p<0.0001$), perceived direction ($\chi^2(16) = 753.9, p<0.0001$), and perceived urgency ($\chi^2(16) = 86.5, p<0.0001$). The categorical nature of the directional patterns mean no linear relationships could exist. Yet there are patterns in the responses. The majority (54.5%) classified the "Whole Seat Pan" haptic cue as a warning while notification was only 9 percent (Figure 21). The other directional patterns were primarily classified as alerts. Similarly, perceived urgency ratings tended to be higher for the whole seat pan than for the other directional patterns (Figure 22). Yet, the "Whole Seat" pattern was less often associated with a perceived direction of threat (36.6% none) (Figure 23). The "Left" pattern (where only the left side of the seat vibrated) was associated with a left-perceived direction of threat by 81.1 percent of participants. The "Front" pattern (where only the front of the seat vibrated) was associated with perceived direction of threat to the front by 57 percent of participants. The "Right-to-Left" pattern (where the vibration started on the right side of seat and moved to the left) had a perceived direction of threat to the "Right" by 53.7 percent of participants. Vibration of the whole seat pan was more likely to be classified as a warning and higher perceived urgency without an indication of direction of threat, while other directional patterns did provide information about direction of threat. This raises the question of whether direction of threat is useful information that helps drivers avoid crashes.

Figure 21. Driver's Classification for Directional Pattern

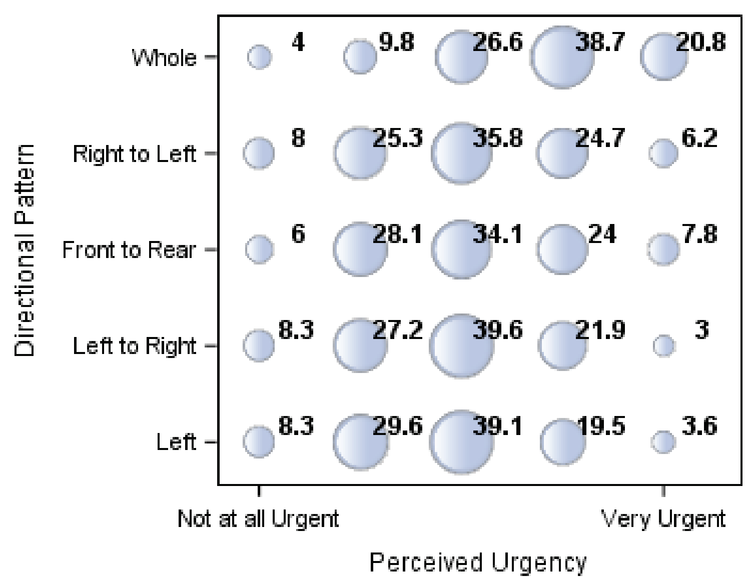

Figure 22. Perceived Urgency for Directional Pattern

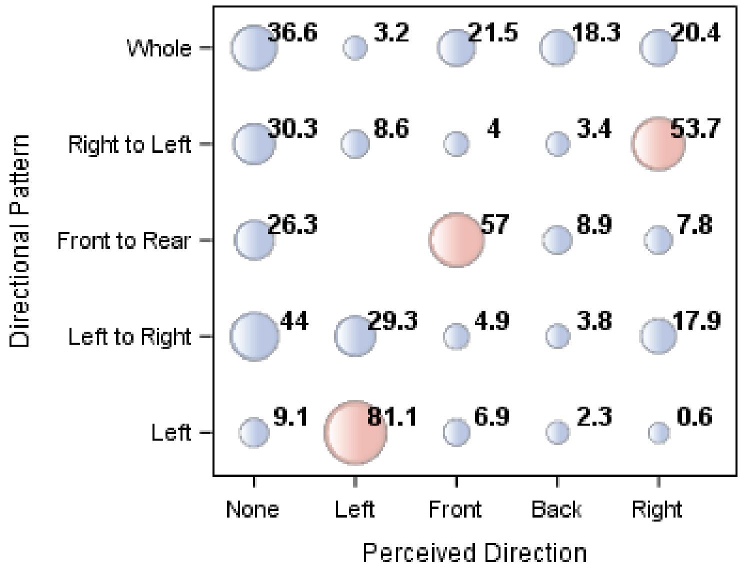

Figure 23. Perceived Direction for Directional Pattern

6.4.2 Outcome

No statistically significant difference was found for directional pattern on crashes ($\chi^2(5) = 1.75$, p=0.8829). The lack of difference in crashes across the directional patterns may indicate that providing directional information does not increase the effectiveness of a haptic cue. Yet the lack of difference from baseline (no alert) for directional pattern and indeed across all three characteristics calls into question vibrotactile seat haptic cues as an effective crash warning interface for the characteristics and levels presented in this study.

Table 14. Crashes by Directional Pattern

Directional Pattern	Baseline	Left	Left to Right	Front to Rear	Right to Left	Whole
# No Crash (%)	11	5	6	6	4	7
# Crashes (%)	13	7	6	6	8	5

6.4.3 Nature of Response

First Response

No statistically significant difference was found for directional pattern on type of first response ($\chi^2(5) = 8.09$, p=0.1525). Yet, the accelerator pedal release count is higher for the "Left to Right," "Front to Rear," and "Whole" seat pan patterns than for the "Left." Looking back at the classification of each of these patterns, there is some consistency (Figure 21). The "Left" pattern was more often classified as a notification (37.2%) or an alert (50%). The "Left to Right," "Front to Rear" patterns were most often classified as an alert (53.5% and 45.6%, respectively). The "Whole" seat pan pattern was most often classified as a warning (54.5%).

Table 15. First Response by Directional Pattern

Directional Pattern	Baseline	Left	Left to Right	Front to Rear	Right to Left	Whole
Accelerator Pedal Release	19	7	10	12	9	11
Accelerator Pedal Press	5	1	1	0	1	1
Brake	0	1	0	0	1	0
Steer	0	3	1	0	1	0

First Avoidance Response

No statistically significant difference was found for directional pattern on type of first avoidance response ($\chi^2(5) = 7.78$, p=0.1689). While not statistically different, for both "Front to Rear" and "Whole" patterns drivers exhibited a higher rate of braking response. The directional patterns that included lateral information also resulted in more steering responses. All the directional patterns resulted in fewer accelerator press responses than the baseline. It may be possible to include directional patterns in haptic cues to induce specific responses even though the severity level of the potential crash situation presented in this study did not allow a reduction in crashes to be seen.

Table 16. First Avoidance Response by Directional Pattern

Directional Pattern	Baseline	Left	Left to Right	Front to Rear	Right to Left	Whole
Brake	16	6	7	9	6	10
Accelerator Pedal Press	5	1	1	0	1	1
Steer	3	5	4	3	5	1

6.4.4 Speed of Response

First Response

No significant effect of directional pattern was found on speed of first response ($F(5,72)=1.25$, p=0.2969). There are two factors to consider. It should be noted that the intensity level of 50 Hz at which the inter-pulse interval levels and the directional patterns were presented may have influenced the speed of response.

First Avoidance Response

No significant effect of directional pattern was found on speed of first avoidance response ($F(5,64)=1.19$, p=0.3264). As with first response, the intensity level and crash situation presented may influence whether differences could be seen even though there were trends in the rate of type of response.

Individual Response Types

No significant effect was found for directional pattern on accelerator pedal release ($F(5,61)=1.28$, $p=0.2830$). No significant effect of directional pattern was found on brake pedal press response time ($F(5,68)=0.61$, $p=0.6900$). No significant effect of directional pattern was found on maximum deceleration ($F(5,72)=1.34$, $p=0.2560$). No significant differences were found in steering response time by directional pattern ($F(5,10)=0.94$, $p=0.4976$). Even though there were trends for more braking responses for some patterns and more steering responses for some patterns, the lack of statistical differences here indicate the magnitude of those responses were not different across the directional patterns and no differences in crashes were seen. No meaningful differences were found in accelerator pedal press by directional pattern due to the small number of responses (four).

6.4.5 Perception of the Alert

No significant effect was found for directional pattern in knowledge of the type of event ($\chi2(4) = 8.36$, $p=0.0792$), ease of interpretation ($F(4,41)=0.59$, $p=0.6700$), usefulness of the warning ($F(4,41)=1.51$, $p=0.2183$), or distractibility of the warning ($F(4,40)=1.79$, $p=0.1502$). These results indicate that even if it is possible to induce specific response types using directional patterns in haptic cues, drivers may not be conscious of the effect on their response.

Chapter 7. Discussion

Three characteristics of haptic cues were presented to drivers through a haptic seat within the context of a potential collision with a left incursion vehicle running a red light. The characteristics investigated within the haptic cue were intensity (frequency), inter-pulse interval, and a directional pattern. Five levels of each characteristic were varied (Table 5). All levels of intensity were presented using the 0 ms inter-pulse interval and the “Left” directional pattern. All inter-pulse interval levels and directional pattern were presented at 50 Hz based on pilot testing results and with the “Left” directional pattern. All directional patterns were presented at 50 Hz and 0 ms inter-pulse interval.

7.1 Driver Perception of Haptic Cue

Lower intensities (frequencies) were perceived to be notifications and less urgent. As the intensity increased, the classification moved toward alert then warning, along with an increase in the perceived urgency. Inter-Pulse interval did not affect driver’s classification of the haptic cue. In fact, for all levels of inter-pulse interval, driver classifications closely resembled the classification at 50 Hz. It seems that intensity is a more important factor in driver perception than inter-pulse interval.

Drivers’ perceptions of the alert collected immediately following the potential collision event did not show any statistically significant differences. Yet, drivers’ subjective evaluation of alerts did reveal patterns in drivers’ perceptions of levels of alert characteristics. Drivers did perceive different directions of threat from the directional patterns. The “Whole Seat” haptic cue was the only directional pattern classified as a warning by drivers and was also perceived to be more urgent. The other patterns were perceived to have moderate urgency. Yet the “Whole Seat” pattern did not convey a direction of threat to drivers, while other patterns did. The results of the subjective assessment show the “Left” pattern conveyed a threat direction to the left of the driver, although the percentage of this response may have been inflated by the drivers’ experience of a left incursion event in the previous drive. The “Front-to-Rear” was perceived as communicating a threat to the front. “Right-to-Left” conveyed a threat to the right.

7.2 Driver Response and Outcomes (Crashes)

Differences in driver perception of the haptic cues did not translate into differences in the nature and speed of their responses, nor the outcomes of the scenario. The general lack of differences from baseline in driver responses calls into question vibrotactile seat haptic cues as an effective crash warning interface for the characteristics and levels presented in this study. Driver first responses were faster with the 30 Hz alert than for other intensities and the baseline, which seems inconsistent with the lower intensities being perceived as notifications and less urgent. Yet, first response is dominated by accelerator pedal release. First avoidance response, which does not include accelerator pedal release, was not different across the intensity levels. The haptic cue at 30 Hz prompted faster accelerator pedal release, yet the driver’s active avoidance responses (i.e., was accelerator pedal release, braking, or steering, or accelerator pedal press) were not faster. Additionally, a difference in outcome (crashes) across the levels of intensity was not seen even though the 30 Hz level showed faster first responses than the baseline and other intensity levels.

Recall that in this scenario the alert was presented one second before the incursion vehicle was visible to the driver. In the baseline condition the driver has no reason to suspect a collision threat and respond until the incursion vehicle is visible. The overall lack of differences in the nature and speed of response, and in outcomes between the baseline and the alert present conditions points to the possibility that drivers do not respond when to an alert when a threat is not visible.

7.3 Considerations and Limitations

There are a few points to consider regarding to the nature and speed of driver responses and outcomes. First, accelerator pedal release takes time. Since the first response measure is dominated by accelerator pedal release, for drivers whose first avoidance response was braking, response times may have been delayed by the time required to release the accelerator pedal. This delay may mask any potential priming of responses. The haptic cue presented at 30 Hz did have a faster first response and may indicate priming driver responses is possible. The alert may have helped drivers' awareness of a threat, yet the timing of the event, three seconds from alert to collision assumed to be typical of V2V systems, may not be a time scale that allows potential differences in nature and speed of response to play out. Yet, even earlier alerts carry with them the concern of being perceived as nuisance alerts as threats may naturally resolve before being apparent to the driver.

The collision scenario presented was a "worst case" scenario, where the incursion vehicle was traveling at the same speed as the driver and there was no reduction in speed or avoidance maneuver taken by the incursion vehicle. When investigating driver responses to an alert, the worst case scenario does not present variations in how the event might unfold if the incursion vehicle behavior included an evasive maneuver. Driver responses and evasive maneuvers are often interactions with those of other drivers, introducing more variance into the collision scenario. The control and repeatability available through simulation provide a consistent presentation of threat for examining driver response.

Due to the nature of a side incursion scenario, collision severity is difficult to examine, as the striking vehicle could be either vehicle and the location of the strike can range from clipping a bumper to full speed strike in the center of the vehicle. It is possible that there were differences in collision severity that are not evident based solely on the driver responses. Priming driver responses may be the primary benefit associated with V2V systems and is not evident in the very controlled "worst case" scenarios without the insights collision severity analysis could provide.

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Appendix A. Inter-Pulse Interval Specification

The original experimental plan included the specification for inter-pulse interval shown in Table 17. All values are in milliseconds (ms). The inter-pulse interval range was 0-100 ms with equal distances of 25 ms between the levels. Pulse durations are adjusted to maintain total alert duration as close to 1,200 ms as possible, with a range of 3 ms (1,198-1,201 ms). The alerts were implemented with a 0 ms onset and offset resulting in a square wave.

Table 17. Original Inter-Pulse Interval Specifications

Inter-Pulse Interval Level	Pulse 1	Inter-Pulse Interval 1	Pulse 2	Inter-Pulse Interval 2	Pulse 3	Inter-Pulse Interval 3	Pulse 4	"Inter-Pulse Interval" 4 (lost alert time)	Total Alert Duration
0	300	0	300	0	300	0	300	0	1,200
25	281	25	281	25	281	25	281	25	1,199
50	262	50	262	50	262	50	262	50	1,198
75	244	75	244	75	244	75	244	75	1,201
100	225	100	225	100	225	100	225	100	1,200

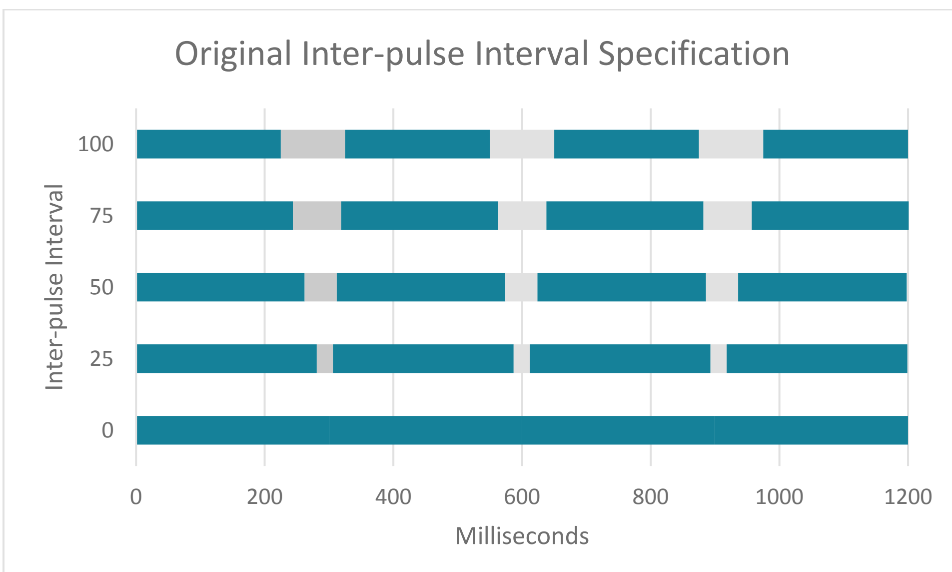


Figure 24. Original Inter-Pulse Interval Specification

A limitation in the tactor software was discovered. Note that, in Table 5, the pulses must begin on a scale of 1 ms. The software operates on two scales 1 ms and 10 ms. We discovered that implementing the alerts at the 1 ms scale resulted the onset and offset of the alerts feeling less clear or crisp than intended.

Three suggested alternative specifications created that could be implemented on the 10 ms scale within the tactor software. These alternatives were presented to NTHSA during a visit to NADS October 16-17, 2017 and discussed with Christian Jerome, research psychologist for NHTSA's Human Factors/Engineering Integration Division, by conference call during the same visit. During that visit, Eric

Traube, general engineer, NHTSA's Human Factors/Engineering Integration Division, experienced all three alternative inter-pulse intervals while driving the NADS-1 simulator. It was determined that Suggestion C would be implemented.

Suggestion A

Suggestion A maintains the same range of conditions from 0-100 ms inter-pulse interval. The difference is in the distance between the levels of inter-pulse intervals, which vary from 20 ms to 30 ms.

Table 18. Inter-Pulse Interval Levels 0-100 ms, Unequal Difference Between Levels

Inter-Pulse Interval Level	Pulse 1	Inter-Pulse Interval 1	Pulse 2	Inter-Pulse Interval 2	Pulse 3	Inter-Pulse Interval 3	Pulse 4	Total Alert Duration
0	300	0	300	0	300	0	300	1,200
20	290	20	290	20	290	20	290	1,220
50	260	50	260	50	260	50	260	1,190
70	240	70	240	70	240	70	240	1,170
100	220	100	220	100	220	100	220	1,180

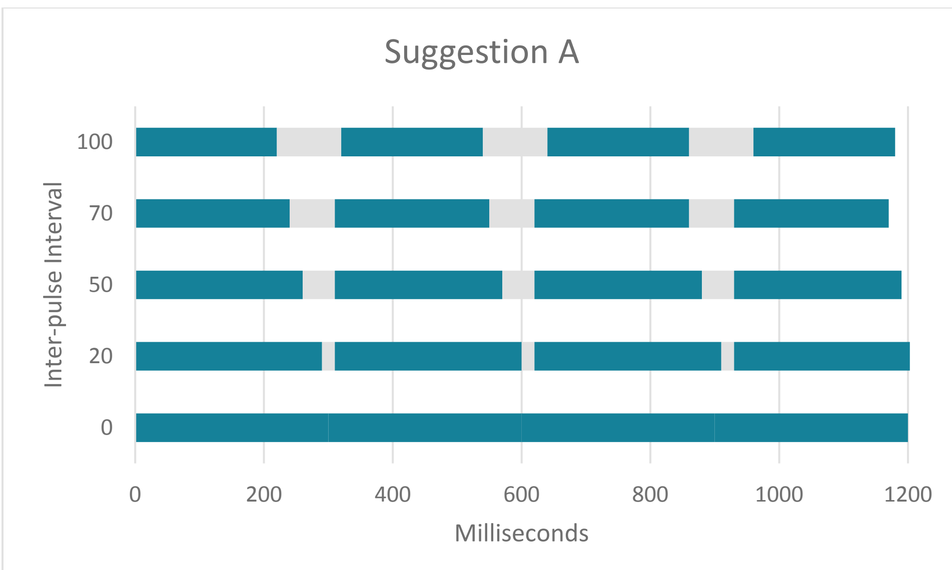


Figure 25. Inter-Pulse Interval Levels 0-100 ms, Unequal Difference Between Levels

Considerations:

- Maintains range
- Difference between levels is not equal
- Difference in total alert duration 50 ms (1,170-1,220 ms)

Suggestion B

Suggestion B decreases range of conditions to 0-80 ms inter-pulse interval yet maintains the distance between the levels of inter-pulse interval at 20 ms.

Table 19. Inter-Pulse Interval Levels 0-80 ms, Equal Difference Between Levels

Inter-Pulse Interval Level	Pulse 1	Inter-Pulse Interval 1	Pulse 2	Inter-Pulse Interval 2	Pulse 3	Inter-Pulse Interval 3	Pulse 4	Total Alert Duration
0	300	0	300	0	300	0	300	1,200
20	290	20	290	20	290	20	290	1,220
40	270	40	270	40	270	40	270	1,200
60	260	60	260	60	260	60	260	1,220
80	240	80	240	80	240	80	240	1,200

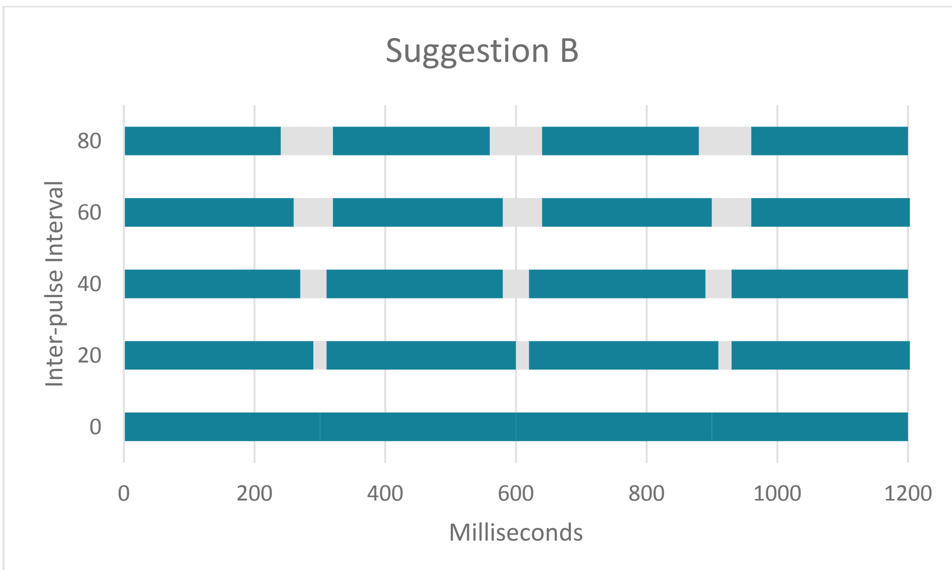


Figure 26. Inter-Pulse Interval Levels 0-80 ms, Equal Difference Between Levels

Considerations:

- Equal distance between inter-pulse interval levels
- Decreased range in inter-pulse interval levels, yet equal between levels
- Smaller differences in total alert duration 20 ms (1,200-1,220 ms)

Suggestion C (NADS preferred choice)

Suggestion C increases range of conditions to 0-120 ms inter-pulse interval yet increases the distance between the levels of inter-pulse interval to 30 ms.

Table 20. Inter-Pulse Interval Levels 0-120 ms, Equal Difference Between Levels

Inter-Pulse Interval Level	Pulse 1	Inter-Pulse Interval 1	Pulse 2	Inter-Pulse Interval 2	Pulse 3	Inter-Pulse Interval 3	Pulse 4	Total Alert Duration
0	300	0	300	0	300	0	300	1,200
30	280	30	280	30	280	30	280	1,210
60	260	60	260	60	260	60	260	1,220
90	230	90	230	90	230	90	230	1,190
120	210	120	210	120	210	120	210	1,200

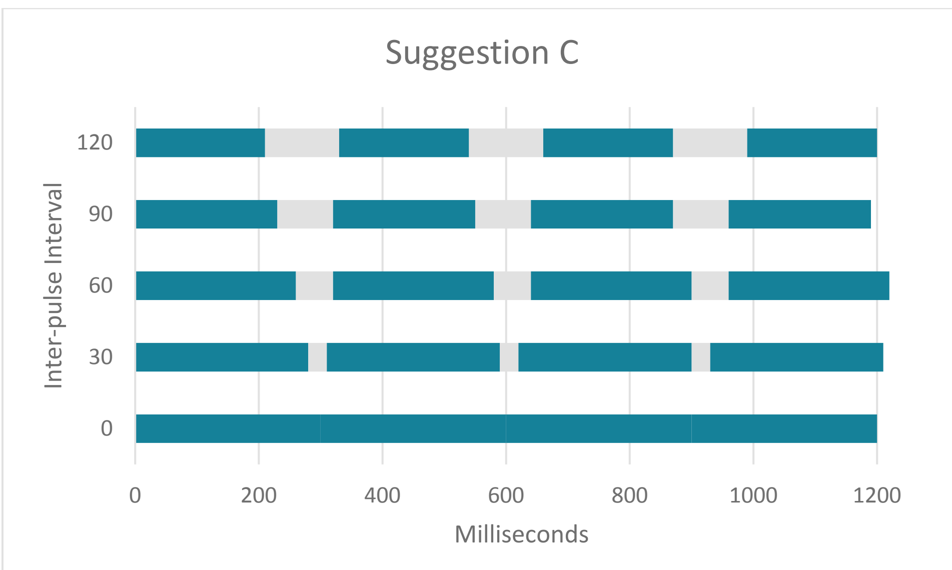


Figure 27. Inter-Pulse Interval Levels 0-120 ms, Equal Difference Between Levels

Considerations:

- Equal distance between inter-pulse interval levels
- Larger range and distance between inter-pulse interval levels, yet equal differences between levels
- Moderate differences between total alert durations 30 ms (1,190-1,220 ms)

Appendix B. Advertising

Webpage Advertisement

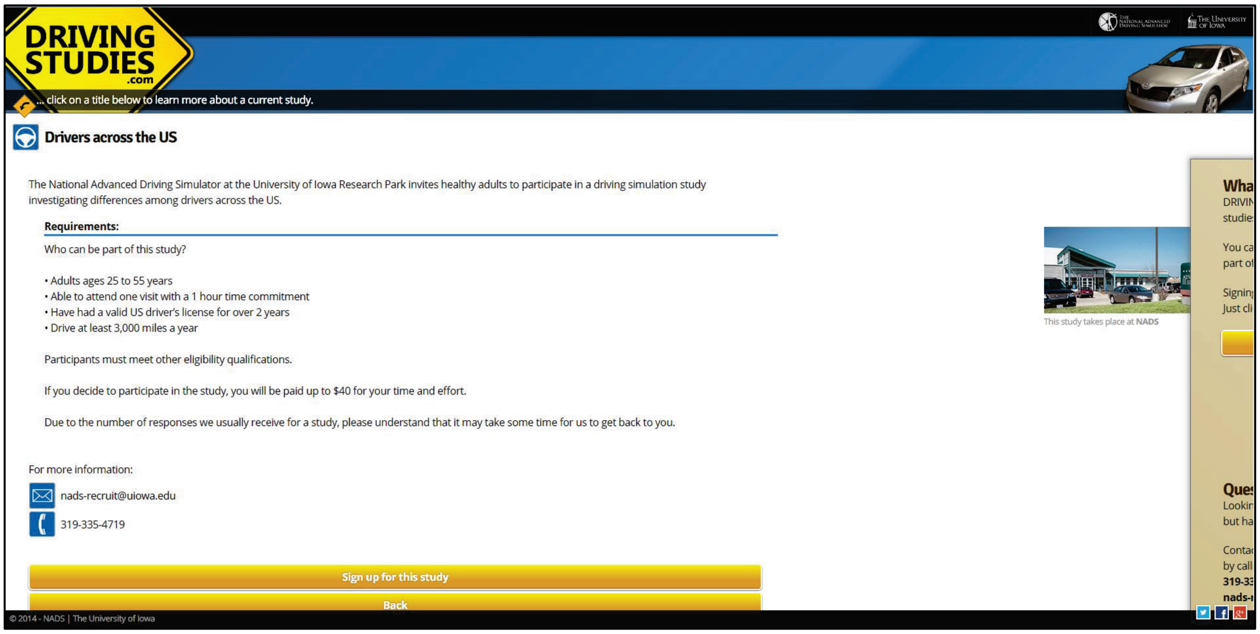


Figure 28. DrivingStudies.com Webpage Advertisement for Study

Registry Blast E-mail

Subject: Participants Invited for Driving Study

Are you interested in participating in a driving research study?

The National Advanced Driving Simulator at the University of Iowa Research Park invites healthy adults to participate in a driving simulation study investigating differences among drivers across the US.

Who can be part of this study?

- Adults ages 25 to 55 years
- Able to attend one visit with a 1-1.5 hour time commitment
- Have had a valid US driver's license for over 2 years
- Drive at least 3,000 miles a year

If you meet the above criteria and are interested in participating, please provide your name, age, and contact information:
Call: 319-335-4719 Or
Email: nads-recruit@uiowa.edu

Mention study name "V2V" when responding.

Participants must meet other eligibility qualifications.

If you decide to participate in the study, you will be paid up to $40 for your time and effort.

Due to the number of responses we usually receive for a study, please understand that it may take some time for us to get back to you.

UI Mass E-mail

Subject: Participants Invited for Driving Study

Are you interested in participating in a driving research study?

The National Advanced Driving Simulator at the University of Iowa Research Park invites healthy adults to participate in a driving simulation study investigating differences among drivers across the US.

Who can be part of this study?

- Adults ages 25 to 55 years
- Able to attend one visit with a 1-1.5 hour time commitment
- Have had a valid US driver's license for over 2 years
- Drive at least 3,000 miles a year

If you meet the above criteria and are interested in participating, please visit the following link to complete an eligibility screening survey:

https://uiowa.qualtrics.com/jfe/form/SV_ePYCe9OSTWavih7

If you have any questions or concerns at any time, please feel free to email us at nads-recruit@uiowa.edu. Please mention study name "V2V".

If you decide to participate in the study, you will be paid up to $40 for your time and effort.

Due to the number of responses we usually receive for a study, please understand that it may take some time for us to get back to you.

Appendix C. Online Eligibility Screening

Info/Inclusion

Thank you for your interest in our research study investigating differences among drivers across the United States. Participation involves one study visit that will last approximately 1-1.5 hours. You will be required to come to the National Advanced Driving Simulator, located in the University of Iowa Research Park on Oakdale Boulevard in Coralville.

At your visit, you will sign a consent form, drive our NADS-1 simulator with motion, and complete a few questionnaires. You will receive instructions regarding driving the simulator cab and study drives at your visit. You will receive $40 for completing all study procedures.

Are you still interested in participating in this research study?

- ○ Yes
- ○ No

Thank you. There are several criteria that must be met for participation in this study. You will be asked several questions to determine your eligibility. You may choose to skip any questions you do not wish to answer. However, this could affect your eligibility. If at any time you do not wish to continue, simply close your browser window.

Do you possess a valid U.S. Drivers' License?

- ○ Yes
- ○ No

Have you been a licensed driver for at least two years?

- ○ Yes

◯ No

Do you have any restrictions on your license?
To confirm, please take out your driver's license. On an Iowa license, the restrictions are listed on the back. A common restriction is for vision correction (restriction B in Iowa).

◯ Yes - vision correction only
◯ Yes - other or other+vision correction
◯ No

Do you drive at least 3000 miles per year?

◯ Yes
◯ No

Do you drive at least once per week?

◯ Yes
◯ No

What is your age?

[ ]

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

◯ Yes
◯ No

Do you have normal or corrected-to-normal hearing?

◯ Yes
◯ No

Do you require any special equipment to help you drive such as pedal extensions, hand brake or throttle, spinner wheel knobs, or other non-standard equipment?

◯ Yes

◯ No

HealthQuestions/ExclusionCriteria

Due to pre-existing health conditions, some people are not eligible for participation in this study. We need to ask you some general health-related questions to further determine your eligibility. Your responses are voluntary and you can refuse to answer any questions.

Are you, or is there any possibility that you are pregnant?

◯ Yes
◯ No
◯ Not Applicable

Do you have Diabetes?

◯ Yes
◯ No

Is your Diabetes Type I or Type II?

◯ Type I
◯ Type II

Is your Type II Diabetes controlled or uncontrolled?

Note: Medication or other means used under the supervision of a physician would count as controlled.

◯ Controlled
◯ Uncontrolled

Do you suffer from a heart condition such as a disturbance of the heart rhythm, or have you had a heart attack or a pacemaker implanted within the last 6 months?

◯ Yes
◯ No

Have you ever suffered brain damage from a stroke, tumor, head injury, or infection?

- ○ Yes
- ○ No

Do you have any of the following lingering symptoms?

- **Vision impairment (blurring, loss, or double vision)**
- **Weakness or numbness in arms, legs, or face**
- **Trouble swallowing or slurred speech**
- **Coordination issues or loss of control**
- **Trouble walking, thinking, remembering, talking, or understanding**

AND/OR

Do you have an active tumor, or have you had a stroke in the past 6 months?

- ○ Yes
- ○ No

Have you ever been diagnosed with seizures or epilepsy?

- ○ Yes
- ○ No

Have you had a seizure in the past 12 months?

- ○ Yes
- ○ No

Do you have Ménière's Disease or any inner ear, dizziness, vertigo, hearing, or balance problems?

Note: Ménière's Disease is a problem in the inner ear that affects hearing and balance. Symptoms can be low- pitched roaring in the ear (tinnitus), hearing loss that may be permanent

or temporary, and vertigo. <u>Vertigo</u> is a feeling that you or your surroundings are moving when there is no actual movement, described as a feeling of spinning or whirling and can include sensations of falling or tilting. It may be difficult to walk or stand and you may lose your balance and fall.

- ○ Yes
- ○ No

Do you currently have a sleep disorder such as narcolepsy or Chronic Fatigue Syndrome?

- ○ Yes
- ○ No

Do you currently have sleep apnea?

- ○ Yes
- ○ No

Is your sleep apnea treated (such as with CPAP) or untreated?

- ○ Treated
- ○ Untreated

Do you currently have anxiety disorder, drug dependency, claustrophobia, ADHD, or untreated depression?

- ○ Yes
- ○ No

Have you experienced any pain from neck or back injuries within the last year?

- ○ Yes
- ○ No

Is it a current or chronic neck or back injury?

- ○ Yes
- ○ No

HealthQuestions/NeedtoFollowUp

Do you have migraine or tension headaches?

- ○ Yes
- ○ No

Have you been diagnosed with a serious illness? For example, cancer, Crohn's disease, Hodgkin's disease, Parkinson's disease, or any condition requiring radiation or chemotherapy treatments.

- ○ Yes
- ○ No

Is the condition still active?

- ○ Yes
- ○ No

Are there any lingering effects?

- ○ Yes
- ○ No

Are you currently receiving any radiation and/or chemotherapy treatment?

- ○ Yes
- ○ No

Are you currently taking any prescription or over-the-counter medications or supplements?

- ○ Yes
- ○ No

What are you currently taking? Please describe the medication or supplements and, if comfortable, provide the reason for taking the medication or supplement.

NonHealthQuestions/NeedtoFollowUp

Do you experience any kind of motion sickness?

- ○ Yes
- ○ No

Please use the slider bars to answer the following two questions about your motion sickness.

	0	1	2	3	4	5	6	7	8	9	10
On a scale of 0 to 10, how often do you experience motion sickness, with 0=Never and 10=Always											
On a scale of 0 to 10, how severe are your symptoms when you experience motion sickness, with 0=Minimal and 10=Completely Incapacitated											

Do you have any mobility issues that would make climbing down a short ladder or walking on a narrow walkway without assistance difficult for you to perform safely?

- ○ Yes
- ○ No

Please use this space for any comments you would like to add about your responses to any of the survey questions.

ContactInfo

Thank you for your responses! A research team member will contact you if you are eligible to continue or if there is a need to follow up due to a survey response. Please provide your contact information in the space below so that we may reach you. If you wish to contact a researcher directly, please email nads-recruit@uiowa.edu and a researcher will get in touch as soon as possible.

First and last name

Phone number(s) with any additional instructions for calling (e.g., best time to call, when to use specific numbers). Please use the format (xxx-xxx-xxxx) when providing your phone number(s).

Email address

Powered by Qualtrics

Appendix D. Phone Screening

V2V Haptic – "Drivers across the US"

Generic Telephone Screening Procedures

For a participant to be eligible for a study they must meet **ALL** of the following criteria:

- Be able to participate when the study is scheduled
- Meet all inclusion criteria
- Pass the phone health screening questions

Instructions to the experimenter are in normal text.
Portions to be read aloud to potential participant are in **bold**.

Overview

> **The purpose of this research study is to investigate differences among drivers across the US.**

Study Information, Time Commitment and Compensation:

> **Participating in this study involves one study visit that will last approximately 1-1.5 hours. You will be required to come to the University Research Park on Oakdale Blvd in Coralville to participate.**
>
> **Participation involves signing a consent form, driving a simulator, and completing some questionnaires. You will receive instructions regarding driving the simulator cab and the study drives at your visit.**
>
> **You will receive $40 for completing all study procedures.**
>
> **Are you still interested in participating?**

- If YES, continue with Inclusion Criteria
- IF NO, **Would you like to be contacted for future studies?**
  - IF NOT interested in future studies and wishes to be deactivated in the registry
    - Make note indicating inactive status is at individual's request
    - Reason if given

Inclusion Criteria ~ General Driving Questions

Overview

Before this list of questions is administered, please communicate the following:

There are several criteria that must be met for participation in this study. I will need to ask you several questions to determine your eligibility.

If an individual fails to meet one of the following criteria, proceed to Closing.

1) **Do you possess a valid U.S. Drivers' License?**
   (must answer yes)

2) **How long have you been a licensed driver?**
   (must be 2 years or longer)

3) **What restrictions do you have on your license?**
   (must have no restrictions other than for corrective lenses)

4) **How many miles do you drive per year?**
   (must be at least 3,000 miles per year)

5) **How often do you drive?**
   (must be at least once per week)

6) **How old are you?**
   (must be age 25 -55 years)

7) **Do you have normal or corrected to normal vision?**
   (must answer yes)

8) **Do you have normal or corrected to normal hearing?**
   (must answer yes)

9) **Do you require any special equipment to help you drive such as pedal extensions, hand brake or throttle, spinner wheel knobs or other non-standard equipment?**
   (must answer no)

If General Inclusion Criteria are met
Proceed to General Health questions below

General Health Exclusion Criteria

Overview

Before administering this list of questions, please communicate the following:

- **Because of pre-existing health conditions, some people are not eligible for participation in this study. I need to ask you some general health-related questions before you can be scheduled for a study appointment.**
- **Your responses are voluntary and all answers are confidential.**
- **You can refuse to answer any questions.**
- **No other responses will be kept.**

1) If the subject is female:
   - **Are you, or is there any possibility that you are pregnant?**

Exclusion criteria:

- If pregnant or there is any possibility of being pregnancy

2) Have you been diagnosed with a serious illness?
   - If YES, **Is the condition still active?**
   - If YES, **Are there any lingering effects?**
   - If YES, **Do you care to describe?**

Exclusion criteria:

- Cancer (receiving any radiation and/or chemotherapy treatment within last 6 months)
- Crohn's disease
- Hodgkin's disease
- Parkinson's disease
- Currently receiving any radiation and/or chemotherapy treatment

3) Do you have Diabetes?

NOTE: Type II Diabetes accepted if controlled (medicated and under the supervision of physician)

Exclusion criteria:

- Type I Diabetes - insulin dependent
- Type II – **Uncontrolled** (see above)

4) Do you suffer from a heart condition such as disturbance of the heart rhythm or have you had a heart attack or a pacemaker implanted within the last 6 months?

If YES
   - **Please describe?**

Exclusion criteria:

- History of ventricular flutter or fibrillation
- Systole requiring cardio version (atrial fibrillation may be acceptable if heart rhythm is stable following medical treatment or pacemaker implants)

5) **Have you ever suffered brain damage from a stroke, tumor, head injury, or infection?** If YES ➢ **What are the resulting effects?** ➢ **Do you have an active tumor?** ➢ **Any visual loss, blurring or double vision?** ➢ **Any weakness, numbness, or funny feelings in the arms, legs or face?** ➢ **Any trouble swallowing or slurred speech?** ➢ **Any uncoordination or loss of control?** ➢ **Any trouble walking, thinking, remembering, talking, or understanding?**
Exclusion criteria: • A stroke within the past 6 months • An active tumor • Any symptoms still exist
6) **Have you ever been diagnosed with seizures or epilepsy?** If YES ➢ **When did your last seizure occur?**
Exclusion criteria: • A seizure within the past 12 months
7) **Do you have Ménière's Disease or any inner ear, dizziness, vertigo, hearing, or balance problems?** NOTE: Wear hearing aids - full correction with hearing aides acceptable If YES ➢ **Please describe.** <u>Ménière's Disease</u> is a problem in the inner ear that affects hearing and balance. Symptoms can be low- pitched roaring in the ear (tinnitus), hearing loss, which may be permanent or temporary, and vertigo. <u>Vertigo</u> is a feeling that you or your surroundings are moving when there is no actual movement, described as a feeling of spinning or whirling and can be sensations of falling or tilting. It may be difficult to walk or stand and you may lose your balance and fall.
Exclusion criteria: • Meniere's Disease • Any recent history of inner ear, dizziness, vertigo, or balance problems
8) **Do you currently have a sleep disorder such as sleep apnea, narcolepsy or Chronic Fatigue Syndrome?** If YES ➢ **Please describe.**
Exclusion criteria: • Untreated sleep apnea • Narcolepsy • Chronic Fatigue Syndrome

9) Do you have migraine or tension headaches that require you to take medication daily?

If YES,

- **Please describe.**

Exclusion criteria:

- Any narcotic medications

10) Do you currently have untreated depression, anxiety disorder, drug dependency, claustrophobia, or ADHD?

If YES,

- **Please describe.**

Exclusion criteria:

- Untreated depression and ADHD
- Dependency or abuse of psychoactive drugs, illicit drugs, or alcohol
- Agoraphobia, hyperventilation, or anxiety attacks

11) Have you experienced any pain from neck or back injuries within the last year?

If YES,

- **Is it current or chronic neck or back injury?**

Exclusion criteria:

- Any current skeletal, muscular or neurological problems in neck or back regions
- Chronic neck and back pain
- Pinched nerves in neck or back
- Back surgery within last year

12) Are you currently taking any prescription or over the counter medications?

If YES,

- **What is the medication?**
- **Are there any warning labels on your medications, such as potential for drowsiness?**

Exclusion criteria:

- Sedating medications or drowsiness label on medication UNLESS potential participant indicates they have been on the medication consistency for the last 6 months AND states they have NO drowsiness effects from this medication

13) Do you experience any kind of motion sickness? If YES ➢ **What were the conditions you experienced: when occurred (age), what mode of transportation, (boat, plane, train, car), and what was the intensity of your motion sickness?** ➢ **On a scale of 0 to 10, how often do you experience motion sickness with 0 = Never and 10 = Always** ➢ **On a scale of 0 to 10, how severe are the symptoms when you experience motion sickness with 0 = Minimal and 10 = Incapacitated**
Exclusion criteria: • One single mode of transportation where intensity is high and present • More than 2 to 3 episodes for mode of transportation where intensity is moderate or above • Severity and susceptibility scores rank high
14) Do you have any mobility issues that would make climbing down a short ladder or walking on a narrow walkway without assistance difficult for you to perform safely?
Exclusion criteria: • none; make note on schedule to ensure extra staff on hand
Proceed to Closing

Closing

<u>MEETS ALL CRITERIA</u>

Instructions:

- **Refrain from drinking alcohol for 24 hours prior to your driving session.**
- **Please avoid taking any NEW prescription or over the counter drugs for the 24 hours preceding your driving session. If you do need to take a new medication 24 hours preceding your driving session, please call us. Ibuprofen, Tylenol, aspirin, and vitamins are acceptable to take prior to driving session.**
- **Bring your Driver's License with you to appointment.**
- **We ask that cell phones and pagers be turned off or left home or in your car outside as they are not allowed while participating in the driving study.**
- **We request the following of all participants:**
  - **Wear flat shoes to drive in**
  - **Do not wear a hat or chew any gum as they are not allowed while driving**
  - **Refrain from wearing artificial scents (perfume or cologne) as some staff are allergic to scents**
- **If your appointment is before 8am or after 5pm, or on a Saturday, the front door may be locked. Please come to the door at your appointment time. Someone should be in the lobby waiting to let you in. If they have had to step away for a moment, they will return as soon as possible.**
- **Please call (319) 335-4666 if you are unable to make this appointment as soon as possible. We prefer 24-hour notice. Please leave a message if you receive voicemail and a staff member will return your call.**

<u>DOES NOT MEET CRITERIA</u>:

- Inform participant that they may qualify for a future study and ask if they wish to remain in our database to be called for future studies.

Appendix E. Informed Consent

INFORMED CONSENT DOCUMENT

Project Title: Drivers across the US

Principal Investigator: Dawn Marshall

Research Team Contact: Dawn Marshall, 319-335-4774
Rose Schmitt, 319-335-4666

This consent form describes the research study to help you decide if you want to participate. This form provides important information about what you will be asked to do during the study, about the risks and benefits of the study, and about your rights as a research subject.

- If you have any questions about or do not understand something in this form, you should ask the research team for more information.
- You should discuss your participation with anyone you choose such as family or friends.
- Do not agree to participate in this study unless the research team has answered your questions and you decide that you want to be part of this study.

WHAT IS THE PURPOSE OF THIS STUDY?

This is a research study. We are inviting you to participate in this research study because you are between the ages of 25 and 55, are a regular driver, and are in good general health.

The purpose of this research study is to examine differences in drivers across the US.

HOW MANY PEOPLE WILL PARTICIPATE?

Approximately 300 people will take part in this study at the University of Iowa.

HOW LONG WILL I BE IN THIS STUDY?

If you agree to take part in this study, your involvement will last for approximately 1 hour during one study visit.

WHAT WILL HAPPEN DURING THIS STUDY?

An experimenter will verbally review this document and answer any questions you have. If you agree to be in the study, you will receive a copy of your signed document at the end of your visit. You will then be asked to show your driver's license so we can confirm it is valid, fill out a payment form and video release statement, and complete a questionnaire that covers some general questions about your demographics (age, gender, ethnicity, vision, and start age of driving). You will then watch a presentation that describes the driving simulator and driving environment.

After any questions have been answered, you will be escorted into the simulator. You will be driving the NADS-1 with full motion. The NADS-1 contains a full size vehicle cab in an enclosed dome with the driving environment projected on the walls around the vehicle. You will be asked to position yourself in the driver's seat and make adjustments as needed so that you are able to drive comfortably. You will next complete one practice drive of approximately 5-6 minutes. Immediately following the end of the drive, you will be asked to complete a wellness survey that asks about how you feel at that moment. After this survey, you will complete a study drive that will last approximately 5-7 minutes. Immediately following the end of the drive, you will be asked to complete a wellness survey that asks about how you feel at that moment. Following the simulator drive and wellness survey, you will be asked to fill out a post-drive survey that asks about specific experiences from your drive. You will next complete one additional study drive and answer questions throughout using a touchscreen located on the center console. Finally, you will complete a short questionnaire about the realism of the simulator. A member of the research team will complete your payment form and the study will be completed.

You may skip any questions you do not wish to answer on any of the questionnaires.

Video Recording

All driving trials will be recorded using digital video/audio recorders that are placed so that we are able to view your face, see your interactions with the vehicle displays and see your view of the scene in front of you. The placement of the cameras will allow the researchers to record the simulator controls and your response to driving events.

The simulator contains sensors that measure vehicle operation, vehicle motion, and your driving actions.

These sensors and video cameras are located in such a manner that they will not affect you or obstruct your view while driving. The information collected using these sensors and video cameras are recorded for analysis by research staff and may be used as described in the Confidentiality section below.

Future Studies

We will keep on file your name and information about you, including birth date, contact phone numbers, the annual mileage you drive each year, and responses to general screening questions. We may contact you later to see if you would be willing to complete questionnaires, interviews, or drives for future studies. Agreeing to participate in this study does not obligate you to participate in any future studies. This will be done as part of a separate process approved by the IRB.

WHAT ARE THE RISKS OF THIS STUDY?

You may experience one or more of the risks indicated below from being in this study. In addition to these, there may be other unknown risks, or risks that we did not anticipate, associated with being in this study.

The risk involved with driving the simulator is possible discomfort associated with simulator disorientation. Some participants in driving simulator studies reported feeling uncomfortable during or after the simulator drive. These feelings were usually mild to moderate and consisted of slight uneasiness, warmth, or eyestrain. These effects typically last for only a short time, usually 10-15 minutes, after leaving the simulator. You should notify the researcher any time you experience these feelings and you may quit driving at any time if you experience any discomfort.

If you ask to quit driving as a result of discomfort, you will be allowed to stop immediately. If you ask to quit driving due to discomfort, you will be escorted to a room, asked to sit and rest, and offered a beverage and snack. A trained staff member will determine when you will be allowed to leave. If you show few or no signs of discomfort, you will be able to go home or transportation will be arranged if you feel you are unable to drive home. If you experience anything other than slight effects, a follow-up call will be made to you 24 hours later to ensure you are not feeling ill effects.

Your safety while driving will be monitored by trained staff. A staff member will be riding with you, and other researchers will be accessible via intercom if necessary.

WHAT ARE THE BENEFITS OF THIS STUDY?

You will not benefit from being in this study. However, we hope that, in the future, other people might benefit from this study because we will have a better understanding of how drivers across the U.S. may drive differently.

WILL IT COST ME ANYTHING TO BE IN THIS STUDY?

You will not have any costs for being in this research study.

WILL I BE PAID FOR PARTICIPATING?

You will be paid for being in this research study. You will need to provide your address so that a check can be mailed to you.

The compensation available for completing all the study procedures is $40. If you are unable to complete the study procedures, your pay will be pro-rated based on the amount of time that you participated. You will earn $10.00 for every 15 minutes of participation.

WHO IS FUNDING THIS STUDY?

The National Highway Traffic Safety Administration (NHTSA) is funding this research study. This means that the University of Iowa is receiving payments from the National Highway Traffic Safety Administration to support the activities that are required to conduct the study. No one on the research team will receive a direct payment or increase in salary from the National Highway Traffic Safety Administration for conducting this study.

WHAT ABOUT CONFIDENTIALITY?

We will keep your participation in this research study confidential to the extent permitted by law. However, it is possible that other people such as those indicated below may become aware of your participation in this study and may inspect and copy records pertaining to this research. Some of these records could contain information that personally identifies you.

- federal government regulatory agencies,
- the study sponsor (NHTSA),
- auditing departments of the University of Iowa, and
- the University of Iowa Institutional Review Board (a committee that reviews and approves

research studies).

To help protect your confidentiality, we will assign you a study participant number that will be used instead of your name to identify all data collected for the study. The list linking your participant number and name will be stored in a secure location and will be accessible only to the researchers at the University of Iowa. All records and data containing confidential information will be maintained in locked offices or on secure password protected computer systems that are accessible to the researchers, the study sponsor, and its agents. Study documents will be kept in a locked cabinet within a secure building that can only be entered by research personnel. After completion of analysis, all hard copies except the Informed Consent Documents will be scanned, placed on a CD and placed into the NADS archival room that has limited access by designated archival personnel. The original Informed Consent Documents will be stored in the NADS archival room that has limited access by designated archival personnel.

The **engineering data** collected and recorded in this study (including any performance scores based on these data) will be analyzed along with data gathered from other participants. These data may be publicly released in final reports or other publications or media for scientific (e.g., professional society meetings), regulatory (e.g., to assist in regulating devices), educational (e.g., educational campaigns for members of the general public), outreach (e.g., nationally televised programs highlighting traffic safety issues), legislative (e.g., data provided to the U.S. Congress to assist with law-making activities), or research purposes (e.g., comparison analyses with data from other studies). Engineering data may also be released individually or in summary with that of other participants, but will not be presented publicly in a way that permits personal identification, except when presented in conjunction with video data.

The **video data** (video image data recorded during your drive) recorded in this study includes your video-recorded likeness and all in-vehicle audio including your voice (and may include, in some views, superimposed performance information). Video and in-vehicle sounds will be used to examine your driving performance and other task performance while driving. Video image data (in continuous video or still formats) and associated audio data may be publicly released, either separately or in association with the appropriate engineering data for scientific, regulatory, educational, outreach, legislative, or research purposes (as noted above). You will be asked to sign a separate consent if you agree to allow us to use your video recordings for these purposes.

The **simulator data** is captured and stored on hard drives located within a limited access area of the NADS facility. Access to simulator data is controlled through permissions established on a per-study basis.

If we write a report or article about this study, or share the study data set with others, we typically describe the study results in a summarized manner so that you cannot be identified by name.

IS BEING IN THIS STUDY VOLUNTARY?

Taking part in this research study is completely voluntary. You may choose not to take part at all. If you decide to be in this study, you may stop participating at any time. If you decide not to be in this study, or if you stop participating at any time, you will not be penalized or lose any benefits for which you otherwise qualify.

Can Someone Else End my Participation in this Study?

Under certain circumstances, the researchers might decide to end your participation in this research study earlier than planned. This might happen if you fail to operate the research vehicle in accordance with the instructions provided, or if there are technical difficulties with the driving simulator.

WHAT IF I HAVE QUESTIONS?

We encourage you to ask questions. If you have any questions about the research study itself, please contact: Dawn Marshall at 319-335-4774. If you experience a research-related injury, please contact Dawn Marshall at 319-335-4774.

If you have questions, concerns, or complaints about your rights as a research subject or about research related injury, please contact the Human Subjects Office, 105 Hardin Library for the Health Sciences, 600 Newton Rd, The University of Iowa, Iowa City, IA 52242-1098, (319) 335-6564, or e-mail irb@uiowa.edu. General information about being a research subject can be found by clicking "Info for Public" on the Human Subjects Office web site, http://hso.research.uiowa.edu/. To offer input about your experiences as a research subject or to speak to someone other than the research staff, call the Human Subjects Office at the number above.

This Informed Consent Document is not a contract. It is a written explanation of what will happen during the study if you decide to participate. You are not waiving any legal rights by signing this Informed Consent Document. Your signature indicates that this research study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Subject's Name (printed): ____

Do not sign this form if today's date is on or after EXPIRATION DATE: 01/10/19.

______________________________ ______________________

(Signature of Subject) (Date)

Statement of Person Who Obtained Consent

I have discussed the above points with the subject or, where appropriate, with the subject's legally authorized representative. It is my opinion that the subject understands the risks, benefits, and procedures involved with participation in this research study.

______________________________ ______________________

(Signature of Person who Obtained Consent) (Date)

Page 5 of 5

Appendix F. Video Release

CONSENT FOR RELEASE OF EDITED/ALTERED VIDEO IMAGE AND AUDIO DATA

I, the undersigned, have agreed to participate in a research project to be conducted at the University of Iowa entitled "Drivers across the US."

The purpose of this research study is to examine differences in drivers across the US. As part of the informed consent form I have signed for that study, I have agreed to allow the University to record and use for research purposes video image data (including my video-recorded likeness) and audio data (including my voice), as well as, in some views, superimposed performance information (referred to below as "the Recording"). The University proposes to edit/alter the Recording so that neither my image nor my voice are identifiable and use the altered Recording for the following non-research purposes:

1) Public release for regulatory purposes to assist in regulating devices;
2) Public release for educational purposes to assist with educational campaigns for members of the general public;
3) Public release for outreach purposes, such as nationally-televised programs highlighting traffic safety issues;
4) Public release for legislative purposes, such as to assist the U.S. Congress with law-making/rule-making activities.

Engineering data may also be released individually or in summary with that of others participating in the study, but will not be presented publicly in a way that permits personal identification.

I hereby authorize the University of Iowa, the study sponsor, and those acting pursuant to its authority, to edit/alter my recorded video image and audio data, with or without related engineering data, so that neither my image nor my voice are identifiable, and to use the Recording so edited/altered for the non-research purposes specified above.

I transfer and assign to the University of Iowa and the study sponsor any right, title, and interest I may have in and to the edited/altered Recording, including the copyright, and in and to all works based upon, derived from, or incorporating the recorded data.

I irrevocably waive any right to inspect, edit, or approve said edited/altered Recording in any of its forms.

I irrevocably release the University of Iowa and the study sponsor, and any of their employees, agents, and assigns, from any and all claims that I may have at any time arising out of, or related to, the edited/altered Recording or use of the edited/altered Recording, including, but not limited to, any claims based on the right of privacy, libel, or defamation.

____

Name of Participant

____

Signature of Participant

____

Date

Appendix G. General Questions

THE UNIVERSITY OF IOWA

What is your age today? (years of age)

[ ]

What is your gender?

- ○ Male
- ○ Female
- ○ Prefer not to respond/other

Of which ethnic origin(s) do you consider yourself? (Check all that apply)

- ☐ American Indian/Alaska Native
- ☐ Asian
- ☐ Black/African American
- ☐ Hispanic/Latino
- ☐ Native Hawaiian/Other Pacific Islander
- ☐ White/Caucasian
- ☐ Other

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

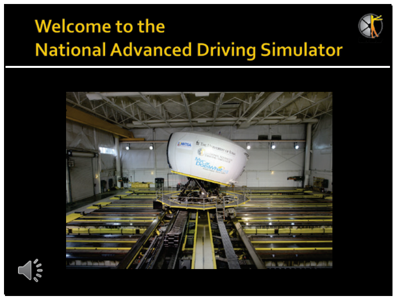
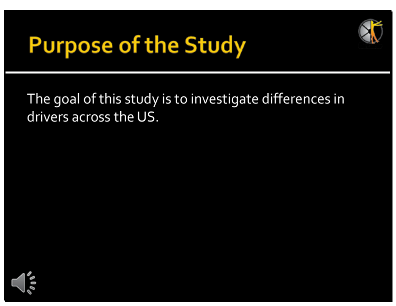
- ○ Normal
- ○ Corrected-to-normal

How old were you when you started to drive any type of vehicle (tractor, car, etc.)? (years of age)

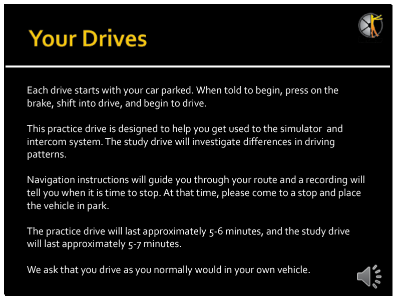
[ ]

BACK NEXT

Appendix H. PowerPoint

	Slide Image	Slide Audio
Slide 1		Welcome to The National Advanced Driving Simulator and thank you for your interest in our study.
Slide 2		We are going to review some information to prepare you for your simulator drives. Each slide will play on its own. Listen to each slide carefully. You may ask questions at the end.
Slide 3		This goal of this study is investigate differences in drivers across the US.

Slide 4



Each drive starts with your car parked. When told to begin, press on the brake, shift into drive, and begin to drive.

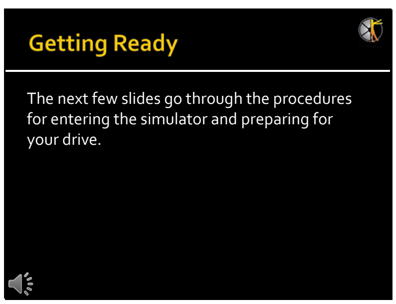
This practice drive is designed to help you get used to the simulator and intercom system. The study drive will investigate differences in driving patterns.

Navigation instructions will guide you through your route and a recording will tell you when it is time to stop. At that time, please come to a stop and place the vehicle in park.

The practice drive will last approximately 5-6 minutes, and the study drive will last approximately 5-7 minutes.

We ask that you drive as you normally would in your own vehicle.

Slide 5

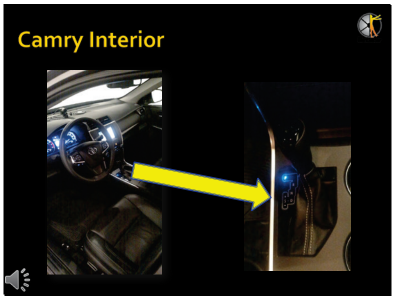


The next few slides go through the procedures for entering the simulator and preparing for your drive.

Slide 6

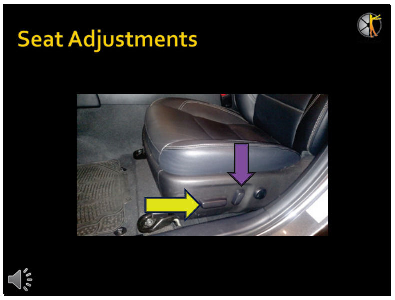
Today you will be driving a 2015 Toyota Camry.

Slide 7



When you are escorted to the simulator, a researcher will open the door for you and at that time you may be seated in the car. The Camry has an automatic transmission and the gear lever is in the center console. The gear shifting pattern can be seen in the picture on the right.

Slide 8

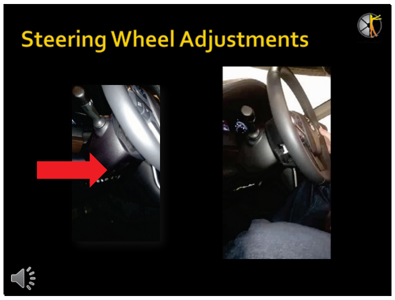


Once you are seated, please adjust the seat and the steering wheel so you are in a comfortable driving position.

The seat position adjustment is the foremost button on the left side of your seat. You can move forward or backward, adjust the seat angle, or adjust the seat height using this button.

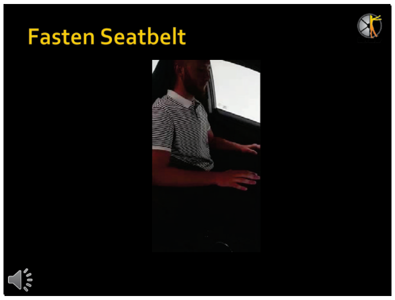
The lever to adjust the angle of the seat back is the vertically oriented button on the left side of the seat.

Slide 9



Adjust the steering wheel so you are comfortable. You must be able to view the speedometer by glancing downward rather than by moving your head. The lever is located above your left knee, in the left center of the steering column. Please adjust the wheel as low as possible while still considering your comfort.

Slide 10

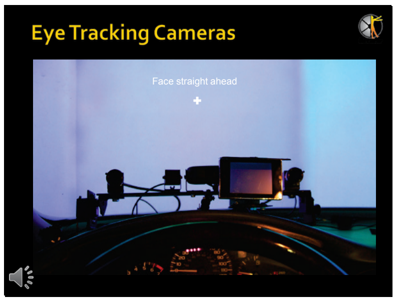


Once the adjustments to your driving position have been made, please fasten your seatbelt. (video)

Slide 11

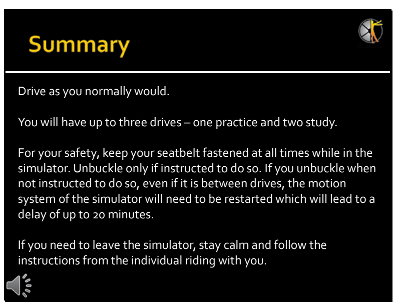
During the time that you are not driving, we ask that you sit in the "resting position", with your hands off of the steering wheel and your feet pulled back and away from the pedals. (video)

Slide 12



After you fasten your seatbelt and are seated in the resting position, we will align the eye tracking cameras. During this process, you should sit in the same position you would if you were driving, facing forward and looking out the front windshield. Then we will take pictures. We will next calibrate the cameras. To calibrate the cameras, you will look into both cameras located on the dash when instructed. For this process you should look into the cameras without moving your head. You'll then be asked to look at a few landmark points and eye tracking will be finished.

Slide 13



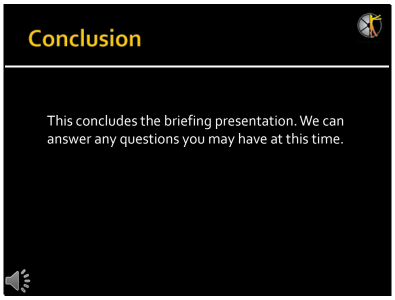
Drive as you normally would.

You will have up to three drives – one practice and two study.

For your safety, keep your seatbelt fastened at all times while in the simulator. Unbuckle only if instructed to do so. If you unbuckle when not instructed to do so, even if it is between drives, the motion system of the simulator will need to be restarted which will lead to a delay of up to 20 minutes.

If you need to leave the simulator, stay calm and follow the instructions from the individual riding with you.

Slide 14



This concludes the briefing presentation. We can answer any questions you may have at this time.

Appendix I. Simulation Sickness Questionnaire

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Select one option for each symptom to indicate whether that symptom applies to you right now.

General Discomfort

None	Slight	Moderate	Severe
○	○	○	○

Fatigue

None	Slight	Moderate	Severe
○	○	○	○

Headache

None	Slight	Moderate	Severe
○	○	○	○

Eye Strain

None	Slight	Moderate	Severe
○	○	○	○

Difficulty Focusing

None	Slight	Moderate	Severe
○	○	○	○

Salivation Increased

None	Slight	Moderate	Severe
○	○	○	○

Sweating

None	Slight	Moderate	Severe
○	○	○	○

Nausea

None	Slight	Moderate	Severe
○	○	○	○

Difficulty Concentrating

None	Slight	Moderate	Severe
○	○	○	○

"Fullness of the Head" - Fullness of the head is an awareness of pressure in the head

None	Slight	Moderate	Severe
○	○	○	○

Blurred Vision

None	Slight	Moderate	Severe
○	○	○	○

Dizziness with Eyes Open

None	Slight	Moderate	Severe
○	○	○	○

Dizziness with Eyes Closed

None	Slight	Moderate	Severe
○	○	○	○

Vertigo - Vertigo is experienced as loss of orientation with respect to vertical upright.

None	Slight	Moderate	Severe
○	○	○	○

Stomach Awareness - Stomach awareness is a feeling of discomfort which is just short of nausea.

None	Slight	Moderate	Severe
○	○	○	○

Burping

None	Slight	Moderate	Severe
○	○	○	○

Vomiting

None	Slight	Moderate	Severe
○	○	○	○

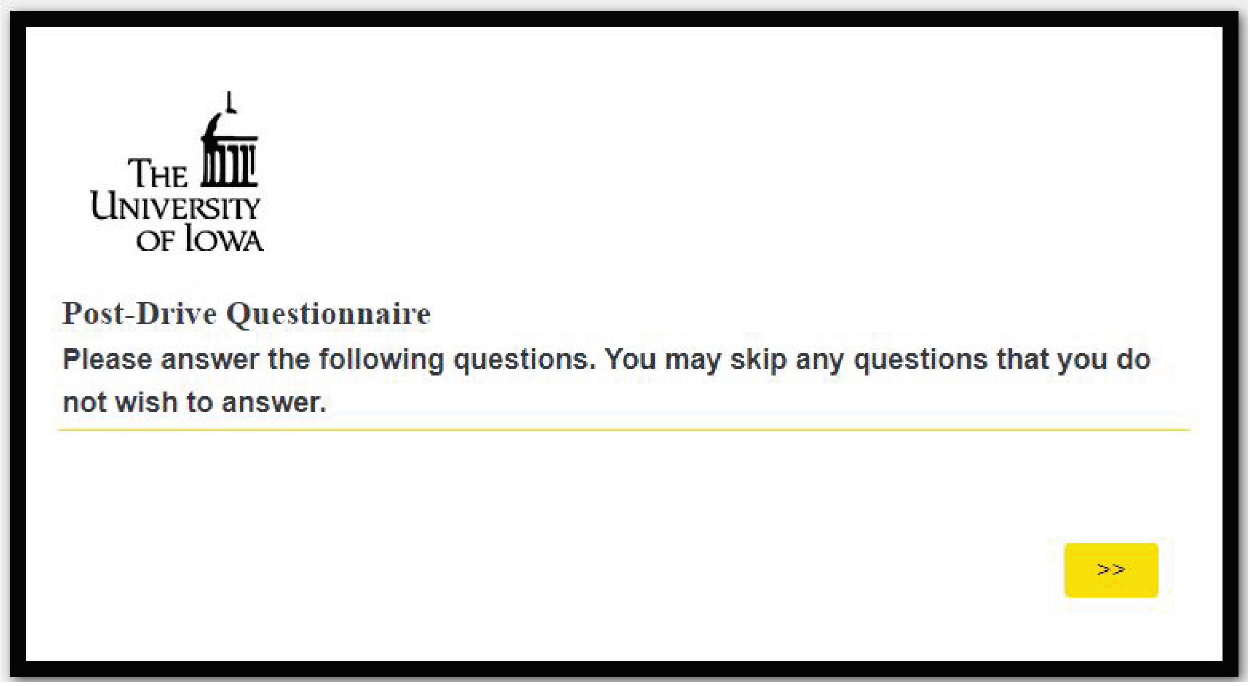
Are you experiencing any other symptoms RIGHT NOW?

○ Yes

○ No

BACK NEXT

Appendix J. Post-Drive Questionnaire



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Did you know what sort of event the warning was trying to alert you to before you saw the other vehicle?

Yes	No
○	○

How easily and quickly could you interpret this warning?

Very Easily/Quickly — Very Difficult/Slowly

1	2	3	4	5

Please rate using this 1-5 scale

How useful was the warning to you in this situation?

Very Useful — Not Useful At All

1	2	3	4	5

Please rate using this 1-5 scale

How distracting was this warning?

Not Distracting At All — Very Distracting

1	2	3	4	5

Please rate using this 1-5 scale

>>

Appendix K. Debriefing

Debriefing Statement

Thank you very much for participating in this study. Your participation was very valuable to us. We know you are very busy and appreciate the time you devoted to participating in this study.

There was some information about the study that we were unable to discuss with you prior to the study drive because doing so may have influenced your actions and thus skewed the study results.

In this study, we were interested in understanding your reactions to an intersection collision warning, known as intersection management assist that involved a vibrating, or haptic, seat. You were told that we were studying differences among drivers across the US; in reality, you experienced one of fourteen warning types when an intersection collision situation was simulated and data about your reaction to the warning modality was collected. It is possible you did not experience a vibration because we also needed to collect baseline information.

We hope this clarifies the purpose of the research, and the reason why we could not tell you all of the details about the study prior to your participation.

It is very important that you do not discuss this study with anyone else until the study is complete. Our efforts will be greatly compromised if participants come into the study knowing its true purpose and how their reactions are being examined. To this end, we would ask that you not discuss any of the details of the study until December 2018.

DOT HS 812 900
March 2020

U.S. Department
of Transportation

National Highway
Traffic Safety
Administration

NHTSA

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