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Auditory Alert Characteristics Impact on Crash Avoidance Warning Response

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16. Abstract
The goal of this study was to understand driver response to a range of auditory characteristic levels, specifically to identify characteristics of a crash warning auditory interface that are measurable and have the potential to provide safety benefits. Drivers were exposed to driving scenarios with potential crash threats in a medium-fidelity driving simulator at five data collection sites, National Advanced Driving Simulator at the University of Iowa, University of Washington, Texas A&M Transportation Institute, Clemson University (Phase 1 FCW only), and Leidos. Three crash scenarios were used: rear-end crash with forward collision warning, junction-crossing crashes with intersection movement assist, and opposite-direction crashes with left turn across path. Auditory characteristics examined were fundamental frequency, duty cycle, and tempo, each at five levels. Results show statistically significant differences between warning characteristics. A fundamental frequency around 234 Hz produced faster response compared to fundamental frequencies over 319 Hz or near 115 Hz. Extremely low duty cycles produced longer reaction times than higher duty cycles. Fundamental frequencies over 319 Hz or near 115 Hz. Extremely low duty cycles produced longer reaction times than higher duty cycles. Slower reaction times were seen for the tempo of 1 pulse per second.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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EXECUTIVE SUMMARY

The objectives of this effort were to examine safety benefits associated with characteristics of crash warnings with a focus on vehicle-to-vehicle (V2V) applications. Specifically, we aimed to identify measurable characteristics of a crash warning auditory interface that have the potential to provide safety benefits. This project used high-priority crash scenarios in the NADS miniSim driving simulator and a multi-site data collection to obtain data from a representative sample. Five data collection sites across the United States provided a diverse driver population, geographic diversity (bi-coastal, southern, and mid-west regions), and a range of population densities and socioeconomic factors. The sites included the National Advanced Driving Simulator (NADS) at the University of Iowa, University of Washington, Texas A&M Transportation Institute, Clemson University (Phase 1 FCW only), and the Reston, Virginia, engineering company Leidos. We identified representative scenarios through the work of Najm, Toma, and Brewer (2013), who reviewed national crash statistics for light-vehicle crashes. The project used three crash scenarios: rear-end crashes with forward collision warning (FCW) that represent 43 percent of V2V pre-crash scenarios, junction-crossing crashes that represent 19 percent of V2V pre-crash scenarios, and opposite direction crashes that represent 13 percent of total crashes while left-turn-across-path (LTAP) crashes comprise the majority of those at 10 percent of total crashes.

This project examined the auditory characteristics of fundamental frequency, duty cycle, and tempo, each at five levels. In this work, fundamental frequency is the lowest frequency present in the auditory alert. Duty cycle is the percentage of time sound is present within an alert. Tempo is the number of pulses of sound per second. We created 13 experimental conditions by varying one characteristic at a time while holding the others constant at a central level. Each scenario used the same 13 alerts. Each participant experienced only one scenario and one alert condition. The central or medium level of each characteristic was used as the baseline in the statistical analysis.

Five sites collected data from 104 participants each for a rear-end collision with FCW scenario for a total of 520 participants. During the FCW event, participants engaged in a distraction task to allow researchers to orchestrate the event and to ensure the driver's response was to the alert. We only used four sites for the junction crossing with intersection movement assist (IMA) and left-turn-across-path scenarios with 52 participants for each scenario at each site for a total of 416 participants. We balanced participants at each site across gender and two age groups (25 to 40 and 41to 55). Each data collection site used the same protocol.

This research focused on how characteristics of auditory alerts affect driver response in connected vehicle forward-crash and intersection-crash situations. Crash situations differed with the FCW event having a distracted driver and a visible threat at the time of alert and with the IMA and LTAP events having no visible threat at the time of alert. Additionally, the LTAP event had the complexity of the driver trying to turn without clear view of the oncoming lane.

The results indicate that despite the same alert characteristics, reaction time varies by type of event. Additionally, changes in alert characteristics do not necessarily lead to similar changes in effect across crash events. The results also indicate that whether the driver crashes may be determined by not only how quickly the driver responds but also by the nature of the response. The results presented have potentially profound impacts on the design of auditory alerts.

The first consideration was the extent to which an alert configuration produces similar responses in different types of event. Ideally, an auditory crash alert should draw the driver's attention to the threat and cause the driver to respond to avoid the crash situation. This is complicated with connected vehicle alerts that may alert the driver to a threat that is not yet visible. Results indicate that when an actual threat is visible, such as the FCW event or a potential threat that can be surmised, such as the LTAP event, drivers respond with similar haste. However, the absence of an obvious threat, such as the IMA event, does not lead to an immediate avoidance response to the alert.

The primary focus of this research is how alert effectiveness varies based on the characteristics of the alert. Results showed that changes in fundamental frequency, duty cycle, and tempo did not produce uniform variations in driver performance measures across scenarios, yet there was some consistency. Similarly, there was not a consistent crash rate across the three types of events due to differences in the kinematics of the driving situations.

For fundamental frequency, three of the levels tested showed increases in reaction time and only one level showed a reduction in crash rate. There was no overlap between these levels that may indicate better overall performance. For fundamental frequency, around 234 Hz provided faster responses, whereas fundamental frequencies over 319 Hz or near 115 Hz did not improve reaction time and reduce crash rate.

For duty cycle, extremely low duty cycles produced an increase in reaction times associated with a 0.05 percent duty cycle. Duty cycles at 25 percent and 75 percent cycles showed a reduction in crash rate yet an increase in reaction time for some situations.

For tempo, there were few consistent responses. Under none of the levels was there a significant change in crash rate. There was, however, some evidence that the lowest level of tempo (1 pulse per second) can slow reaction time.

1 INTRODUCTION

Vehicle-to-vehicle (V2V) technologies will enable, over a secure network, the exchange of raw data between and among vehicles (vehicle's latitude, longitude, heading angle, speed, etc.). This raw data goes to the connected vehicle processor where the safety applications perform their calculations. The system will not necessarily present the raw data to the driver in this form; the V2V system must take the raw data received from the network and transform it into useful information, managing the information based on importance and presenting that information to the driver in an effective way.

Being the sole mechanism by which the driver receives information from the safety system, the driver-vehicle interface (DVI) directly affects the driver's response to the information from the system. Characteristics of the DVI can affect the driver's response, depending on human abilities and limitations (Sanders & McCormick, 1993). The safety benefits of crash warning systems are based on how well they address the target safety need and the overall effectiveness of the system. 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 a primary factor in the effectiveness and benefits of the system. Minimum performance levels may define characteristics of the DVI to ensure safety even when design specifications are not dictated.

In a recent report summarizing the readiness of V2V technology, NHTSA concluded that the interface warning was very important for V2V safety, but posed challenges for the agency (Harding et al., 2014). The report suggested that NHTSA needed more data to understand how the interface affects driver response. The report recommended that NHTSA obtain additional research and analysis on DVI warning characteristics that can effectively enable drivers to react appropriately and avoid the crash. Further, this research should consider the safety problem and a representative sample of U.S. drivers.

The main goal of the current project is to address the research gap identified by NHTSA, specifically to provide the data from a representative sample of drivers and crash scenarios to help better understand driver response to the crash warning (CW) DVI. Of particular interest in this project is data to help determine performance criteria that specify the minimum level of performance for an effective CW DVI for V2V safety applications (i.e., drivers will be able to interpret the warnings and react in a manner so as to avoid the crash). This research aims to determine objective, repeatable, and measureable characteristics of the CW DVI that have the potential to provide safety benefits and to explore possible CW DVI characteristic minimum performance criteria.

The selected approach provides data from a cross section of the country in an effort to provide a representative sample. Additionally, the selection of three different crash types provides a robust and representative sample of situations in which the driver might need to be alerted by a V2V system. The consideration of a range of alert characteristics across sites and crash types results in a large sample size to adequately address the research questions. Although the sample size is quite large, it is still limited when considered in the context of the sample size for individual cells in the analysis, which limits the power of the analyses.

This report provides a summary of the work completed in this project. The report first summarizes the background including crash statistics and auditory alert characteristics. The report then provides an overview of the methodology and data analysis approach. The report presents the results by type of CW system. Finally, the report summarizes the key results from the study.

2 BACKGROUND

This project focuses on V2V applications in light vehicles. To identify representative crash scenarios, the research team consulted work from the Volpe National Transportation Systems Center on pre-crash scenarios and associated applications to identify specific scenarios for inclusion. The research team then consulted work from the Crash Warning Interface Metrics (CWIM) 3 program to specify protocol and event details (Lerner et al., 2011). The research team conducted the project in two phases with the first focused on rear-end crash scenarios and the second focused on intersection crash scenarios.

2.1 The Safety Problem

Najm, Toma, & Brewer (2013) reviewed national crash statistics for light vehicle crashes from 2004 to 2008. They developed a list of prioritized pre-crash scenarios that included five categories specifically relevant to V2V applications: rear-end, lane change, opposite direction, left-turn-across-path – opposite-direction, and junction crossing.

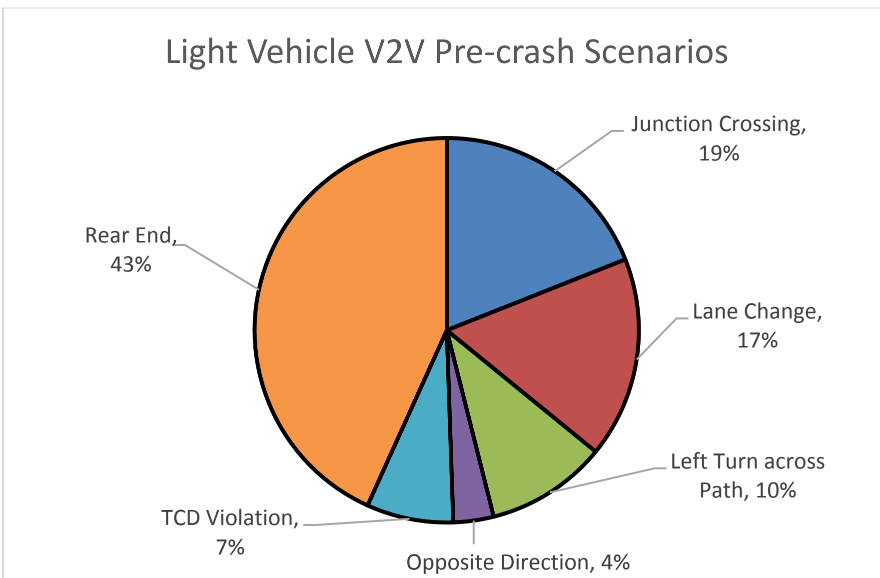

Figure 1 Percentage of total crashes by pre-crash scenario

2.1.1 Rear-End Crashes

Rear-end crashes represent 43 percent of V2V pre-crash scenarios. Within this group, three scenarios exist: lead-vehicle-stopped and two vehicle-moving scenarios, lead-vehicle-decelerating and lead-vehicle-moving at a slower constant speed. The stopped-lead-vehicle scenario, with a posted speed limit of 35 mph, represents the largest percentage of rear-end crashes (57.2%). This speed limit poses a problem for evaluating V2V safety systems, specifically FCW since most FCW systems do not function below 35 mph. To address this issue, the research team chose a lead-vehicle-decelerating scenario from the two lead-vehicle-moving scenarios where crashes are typically associated with a higher posted speed limit, such as 55 mph, and which represent 24.2 percent of rear-end crashes.

2.1.2 Junction-Crossing Crashes

Junction-crossing crashes represent 19 percent of V2V pre-crash scenarios. Within this group, the straight-crossing-path scenario represents 89.5 percent of crashes. The scenario chosen involves the cross traffic running a red light. An IMA system was employed in this scenario.

2.1.3 Left Turn Across Path

Opposite-direction crashes represent 13 percent of total crashes while left-turn-across-path (LTAP) crashes comprise the majority of those at 10 percent of total crashes. Crashes at signalized intersections comprise a slight majority at 52.6 percent of LTAP crashes. The LTAP scenario chosen involves the driver stopping at a red signal in a left-turn lane. Once the left-turn signal changes to green, an oncoming vehicle runs a red light. An LTAP warning system was employed in this scenario.

2.2 Safety Applications

This project considered three safety applications based on the identified safety problems.

2.2.1 Forward Crash Warning

Historically these systems used vehicle sensor data to track vehicles in front of the driver and then to issue warnings. The number of vehicles tracked was limited by the system hardware and many simplifying assumptions were needed to distinguish between vehicles and stationary objects. V2V-based FCW warnings can use data directly from other vehicles, including data that is not available from vehicle sensors, such as pedal force. One of the key V2V advantages is that warnings can be provided sooner and that it can warn about crash situations that are not yet visible to the driver.

2.2.2 Left Turn Across Path

These systems are designed to warn a driver who is attempting to turn left that there is oncoming traffic that would make the turn unsafe. The system warns when it determines that a collision will occur unless the driver responds. These V2V systems provide warnings even when the oncoming vehicle is not visible to the driver.

2.2.3 Intersection Movement Assist

These systems warn the driver about intersection crashes. Two common scenarios are the situation where the driver is stopped at an intersection before proceeding and when the driver is proceeding through an intersection without stopping. In either case, the system warns the driver that a vehicle is on a collision course with them in the intersection and a driver response is required. In some cases, this can be associated with an incurring vehicle that does not stop at a controlled intersection.

2.3 Crash Warning Driver Vehicle Interface Modalities

In pre-crash situations, an alert directs the driver's attention back to the roadway so that drivers may respond appropriately to the unfolding situation. Three commonly used alert modalities available in light vehicles include visual, tactile or haptic, and auditory. This project began with only the rear-end crash scenario and an FCW system and chose alert modalities and characteristics representative of those commonly employed in these types of warning systems designed to mitigate these crashes.

The Society of Automotive Engineers (2003) has defined auditory alerts as an appropriate modality for an FCW system. Additionally, the SAE (2003) recommends that visual alerts should only be used if paired with an auditory alert. Visual alerts, when presented alone, may go unnoticed by drivers when they direct their visual attention away from the location of the visual icon (Curry, Bloomer, Greenberg, & Tijerina, 2009). For example, when a driver looks down and to the right, he or she may not notice a visual-only alert on the vehicle dashboard. Additionally, a visual-only alert may divert a driver's attention toward the alert rather than toward the roadway, as several visual icons exist on a vehicle dashboard and when one illuminates, the driver must direct visual attention to that icon, identify which icon illuminated, and determine its meaning.

Haptic or tactile alerts are a vibration of a portion of the vehicle the driver is in direct contact with, such as the seat, steering wheel or pedal. If the driver is not in direct contact with the specific portion of the vehicle at the time an alert is issued, the alert may be missed entirely by the driver. Equipment to produce haptic alerts does not exist in all vehicles. Additionally, within the context of a research study, clothing layers and thickness may impact driver sensitivity to this type of warning system alert. In comparison, auditory alerts are most prevalent in cars for collision warning systems and their characteristics can be consistently manipulated.

Auditory alerts are recommended for FCW systems in combination with a visual alert (SAE, 2003). The equipment to produce an auditory alert is prevalent in vehicles. Auditory alerts do not necessitate the driver to direct their attention to a location inside the vehicle to identify the alert's meaning. For these reasons, the scope of this research project was limited to auditory warning characteristics. Additionally, speech-based alerts and distinctiveness of alerts are beyond the scope of this work.

Junction crossing and LTAP crash scenarios were added in the second round of data collection. In order to maintain comparability across the first and second rounds of data collection, the same alert modalities and specific characteristics were also used for the IMA and LTAP protocol. This allows for a more overall evaluation of alert characteristics across different collision warning systems.

2.4 Auditory Alert Characteristics

The goal was to identify measurable ranges of characteristics that might provide a safety benefit and ranges that might be a safety concern (i.e., not eliciting an effective driver response). Studies examining the potential benefit of in-vehicle safety systems have typically compared the safety benefits between different alert modalities rather than between different levels of a single alert characteristic within a single modality. Some examples include:

- A combination auditory/visual alert resulted in larger minimum time to collisions than either haptic (brake pulse) or baseline conditions (Lerner et al., 2011);
- A combination of visual icon, sound, seat vibration, and brake pulse together resulted in faster brake reaction times than when a visual icon alone was combined with each (Lee, McGehee, Brown, & Marshall, 2006); and

- Among a head-up display (HUD) visual alert, an auditory beeping alert, a seatbelt tensioning device, or a combination of two or all three of these alerts, the seatbelt tensioning device was the most effective (Forkenbrock, Snyder, et al., 2011).

At the time the research team selected the experimental conditions and protocol for this project, no studies were found comparing driver performance response time across levels of auditory alert characteristics. To address this gap, the research team developed another method of identifying appropriate characteristics and levels. Edworthy, Loxley, and Dennis (1991) and Edworthy and Adams (1996) propose urgency mapping, the concept that matches the perceived urgency of an alert with the urgency of the situation signaled by the alert as a method for identifying auditory characteristics and levels for crash scenarios. The perceived urgency associated with an auditory alert is a subjective measure based on how individuals perceive the auditory alert tone. This subjective measure can be manipulated by changing the physical characteristics of an alert, such as the sound pressure or intensity, frequency, or the inter-pulse interval.

2.5 Identifying Alert Characteristics

The research team identified auditory alert characteristics that affect perceived urgency of an alert through a literature review. The team then prioritized these auditory alert characteristics through consultation with Carryl Baldwin at George Mason University on work conducted within the CWIM program and later published in Driver-Vehicle Interfaces for Advanced Crash Warning Systems: Research on Evaluation Methods and Warning Signals (Lerner et al., 2015).

The perceived urgency associated with an auditory alert is a subjective measure based on how individuals perceive the auditory alert tone, which can be manipulated. People respond more quickly to alerts that sound more urgent (Burt, Bartolome, Burdette, & Comstock, 1995; Edworthy, Helier, Walters, Weedon, & Adams, 2000; Haas & Casali, 1995; Haas & Edworthy, 1996). There is a substantial research base that shows differing levels of auditory alert characteristics are associated with different levels of perceived urgency. Example effects include:

- Alert tones with higher fundamental frequency are perceived as more urgent (Edworthy et al., 1991; Hellier, Edworthy, & Dennis, 1993; Marshall, Lee, & Austria, 2007);
- Shorter inter-pulse intervals produce alert tones with higher perceived urgency (Haas & Casali, 1995; Haas & Edworthy, 1996; Hellier et al., 1993; Marshall, Lee, & Austria, 2007);
- Amplitude envelopes (onset and offset profiles) affect perceived urgency with no onsets having greater urgency than slow onsets which, in turn, have greater urgency than slow offsets (Edworthy, Loxley, & Dennis, 1991; Marshall, Lee, & Austria, 2007); and
- Higher intensity (loudness) levels for alerts are perceived as more urgent (Haas & Casali, 1995; Haas & Edworthy, 1996).

Auditory alert characteristics are arranged by a range of perceived urgency ratings in Table 1, with those with larger ranges on top. Characteristics of auditory alerts can be thought of as falling into three categories. There are characteristics that create an identifiable sound, such as fundamental frequency and harmonic series. Changing these characteristics produces alerts that are perceived as different sounds. The base sound can then be arranged into pulses with characteristics such as inter-pulse interval (silence between pulses of sound) and amplitude envelopes. Pulses can then be arranged into one or more bursts of sound with intervals of silence between the bursts (inter-burst interval) to create an alert. The characteristics listed in Table 1 represent a mixture of those that determine the base sound, the pulse and the burst that comprise an auditory alert.

Table 1 Auditory Alert Characteristics and Perceived Urgency Rating

Characteristic	Influence on Perceived Urgency
Burst Speed	Fast > Moderate > Slow[a]
Inter-pulse Interval	Shorter > Longer (9 ms to 475 ms)[b]
Intensity	Higher > Lower (66 dB to 84 dB)[c]
Amplitude Envelope (pulse)	Regular > Slow On > Slow Off[a]
Harmonic Series	Random > 10% Irregular > 50% Irregular > Regular[a]
Number of Units (burst)	4 units > 2 units > 1 unit[a]
Fundamental Frequency	Higher > Lower (150 Hz to 350 Hz)[a]
	Higher > Lower (210 Hz to 680 Hz)[a]
Speed Change	Speeding up > Regular > Slowing[a]
Musical Structure	Atonal > Unresolved > Resolved[a]
Delayed Harmonics	Absent > Present[a]
Pitch Range	Large > Small > Moderate[a]
Rhythm	Regular > Syncopated[a]
Pitch Contour	Random > Up/Down[a]
a) Edworthy et al. (1991); b) Baldwin and Lewis (2014); c) Lerner et al. (2015)	

Another aspect of perceived urgency is whether or not drivers would identify a sound as an alert indicating an urgent situation. As part of the CWIM program, Lerner et al. (2015) conducted a series of experiments to identify the levels of alert characteristics where sounds would be classified by drivers as highly urgent collision alerts rather than less urgent notifications. In their study, the mean values at which participants identified sounds as time-critical alerts were base frequency (931.71 Hz), tempo or inter-burst interval (330 ms), pulse duration (460 ms), and pulses per burst (2.73). These values may be different from recommended levels, yet represent starting points used in this research for identifying ranges of auditory characteristics that would span the transition point between effective alerts and ineffective alerts. The lowest frequency present in a tone is similar to fundamental frequency. Since fundamental frequency is the characteristic explored in the body of research investigating perceived urgency, we identified it as a characteristic to be explored in this effort. Fundamental frequencies just above and below the mean level identified for time-critical alerts were explored since an upper limit was not identified.

The lowest frequency present in a tone (Lerner et al., 2015) is related to, yet different from, fundamental frequency. Examining a tone easily reveals the lowest frequency present, the method used by Lerner et al., yet this lowest present frequency may not be the fundamental frequency. The lowest frequency present may result from one of several fundamental frequencies which may or may not be present in the tone. For example, a lowest present frequency of 250 Hz may result from a fundamental frequency of 50 Hz or 125 Hz since 250 Hz is a multiple of both 50 Hz and 125 Hz. Since fundamental frequency is the characteristic explored in the body of research investigating perceived urgency and is more easily manipulated, we identified it as a characteristic to be explored in this effort.

Pulse duration and pulses per burst are both temporal parameters of auditory alerts, as are inter-pulse interval and inter-burst interval. Since these parameters are similar at the pulse or burst level, we chose to examine characteristics that encompass both. We combined these parameters into overall characteristics of alerts in the duty cycle (percentage of time sound is present) and tempo (number of pulses per second). Marshall, Lee, and Austria (2007) determined that people perceived longer pulse durations and shorter inter-pulse intervals as more urgent. Together these parameters determine the duty cycle. Duty cycle equals the total pulse duration divided by the sum of the total pulse duration and the sum of the inter-pulse intervals. Marshall, Lee, and Austria (2007) determined that people perceive a higher duty cycle as more urgent.

Inter-pulse interval determines the tempo, defined as the pulses per second, of a sound. A shorter inter-pulse interval produces a faster tempo. Holding duty cycle constant and manipulating tempo creates sounds perceived as faster or slower. The CWIM project determined that manipulating tempo influenced whether sounds were categorized as highly urgent collision alerts rather than less urgent notifications.

3 METHODOLOGY

This section describes the methodology for the project including the scope of CW DVI characteristics, apparatus, experimental designs, and conditions. The first phase of this project involved the collection of data at five sites across the United States for the rear-end with FCW scenario with a total of 520 participants, 104 at each site completing experimental procedures. The second phase only included four data collection sites for the junction crossing with IMA and LTAP scenarios with a total of 416 participants completing the experimental protocol, 52 participants in each scenario at each site. Participants were healthy men and women who held a valid driver's license from 25 to 55 years old. Section 3.6 describes inclusion and exclusion criteria. The independent variables are alert characteristics (fundamental frequency, duty cycle, tempo) and urgency levels (five levels: low-low, medium-low, medium, medium-high, high-high). The goal was to collect a representative sample across the United States. To this end, as many participants as possible were enrolled within the scope of study. Researchers conducted a preliminary power analysis prior to data collection for the FCW scenario based on estimated response data. The analysis revealed that the planned sample size could detect a medium effect size. Based on a preliminary analysis of the FCW data, the LTAP and IMA scenarios had a lower sample size that allowed data collection with these two additional scenarios because no differences between data collection sites were expected.

3.1 Levels of Auditory Alert Characteristics

The scope of this project allowed for the inclusion of three alert characteristics, each at five levels. Based on the body of literature on perceived urgency and the work that was part of the CWIM program, the three characteristics explored in this effort were: fundamental frequency, duty cycle, and tempo. To reflect a large range of perceived urgency, we chose five levels of each characteristic. Prior research predicted that the levels of characteristics associated with low levels of perceived urgency produce slower driver response times to alerts than characteristic levels associated with higher levels of perceived urgency. To identify measurable ranges of characteristics that might provide a safety benefit and ranges that might be a safety concern (i.e., not eliciting an effective driver response), we included levels of alert characteristics that were expected to be less effective and produce slower driver responses.

Based on values explored in the perceived urgency literature and the CWIM program, we selected preliminary levels for each characteristic. We included these levels in a pilot study at the National Advanced Driving Simulator (NADS) to test the experimental protocol, scenarios, and driver responses to the chosen levels. The range of fundamental frequency explored in perceived urgency body of literature was 150 Hz to 680 Hz, with the higher frequencies being associated with higher perceived urgency. Duty cycles ranged from 0.1 to 0.9 and tempo ranged from 2 to 8 pulses per second represent a wide range of potential values. We analyzed driver response data from the pilot and identified no significant differences between the levels of characteristics. Based on the pilot results, we expanded the ranges of all three characteristics. We accomplished this by keeping the central point of each range the same and expanding the extreme levels. Table 2 shows the levels of each characteristic evaluated in the main data collections. The sound levels for each miniSim were calibrated relative to a constant and consistent sound. This ensured that each alert level is consistent.

Table 2 Levels of Alert Characteristics

	Low-Low (LL)	Medium-Low (ML)	Medium (MM)	Medium-High (MH)	High-High (HH)
Fundamental Frequency	115 Hz	234 Hz	319 Hz	641 Hz	963 Hz
Duty Cycle	0.05	0.25	0.5	0.75	0.95
Tempo	1	2	4	8	12

3.2 Apparatus

All data collection sites used identical ¼-cab miniSims with 42-inch 720p plasma displays, Figure 2. The miniSims include three screens (each 3.0 feet wide by 1.7 feet tall) placed 4 feet away from the driver's eye point. This configuration produces a horizontal field of view of 132 degrees and a vertical field of view of 24 degrees. Before the study, we upgraded the hardware and software at each site to the most recent version of the miniSim software, comparable cab interface boards, steering encoders, and sound cards to ensure the same data collection apparatus at each site. Each site used sound calibration procedures to ensure consistent presentation of auditory alerts across sites. Section 3.3 below describes these procedures.

Figure 2 miniSim driving simulator with a quarter cab

3.3 Creation of Auditory Alerts

The sounds were produced using a program called MakeWaves that was written by David Muller, March 11, 2014, using Visual Basic language (VB.net). MakeWaves provides a Windows form which is used to enter the parameters for each sound. The data in the form is loaded from or saved to a text file for archiving and traceability. MakeWaves then renders the text files into wave (.wav) files for playing in the simulator. The wave files are uncompressed, 16 bit, 48,000 samples per second.

The parameters used for each sound include: number of bursts, inter burst interval, pulses/burst, inter pulse interval, pulse duration, pulse frequency, onset time, offset time, first pulse attenuation, amplitude, cutoff frequency, and spectrum file. The spectrum file parameter opens a text file of harmonic number, phase and amplitude. This allows for tones of any harmonic structure to be rendered. All sounds for this study used the spectrum of a saw tooth wave, which consists of all harmonics with descending amplitudes. MakeWaves renders the sounds by summing the values of the cosine waves for each harmonic in the spectrum file. This guarantees there are no inharmonic aliasing effects caused by the interference of the sample rate with the frequency of the tone. Only the harmonics whose frequency values were below the cutoff frequency were rendered. MakeWaves notifies the user if any of the sounds exceed the maximum level allowed by the wave file, to ensure none of the sounds are clipped or distorted.

3.4 Calibration and Measurement of Sound Levels

Each research site, in coordination with the NADS, insured installation of the software and hardware necessary for this data collection on miniSims at each of the five data collection sites. We coordinated schedules to plan this installation immediately prior to the beginning of data collection at each site to minimize the possibility of changes to specific or global settings within the miniSim software and hardware between calibration and data collection. We defined a constant and consistent sound for the calibration of the sound levels for each miniSim. This ensured that each alert level was consistent.

3.4.1 Consistency Across Data Collection Sites

Principal investigators for each data collection site discussed with the overall Principal Investigator the potential differences of data collection areas amongst data collection sites and the protocol for this study. For each data collection site, the team developed and implemented measures to address concerns. Staff involved in research involving human subjects understood the effect sound can have on data collection and each site attempted to minimize ambient or background noise. Additionally, 45 CFR 46 for human subjects' data collection requires privacy which includes the use of isolated locations away from potential sources of ambient noise, such as machinery, person to person conversation, and noises from outside the building. The driving simulator was in a separate room at all data collection sites, minimizing the potential sources of ambient noise.

Another potential source of differences were the characteristics for the simulator data collection rooms. Room configurations affect perceived sound intensity levels, yet the closer the speaker is to the participant's head, the less potential effect of room configuration. To compensate for this, the configuration of these miniSims included placing the speakers 48 inches from the expected driver's head position. The exact measurement varied based on the preferred seat position within the driving simulator, much like a driver's position within a vehicle. This small variation in speaker distance was necessary to allow participants to adjust the seat to a comfortable driving position, thus allowing realistic accelerator release and braking response times. The minor differences in room configuration did not significantly change the measured sound level readings across sites.

At the beginning of each day and again after any significant breaks in data collection, researchers conducted sound calibration procedures. These procedures documented that the ambient noise level in the data collection room was less than 69 dB and alerts during participants' study drives were presented at 75 dB. Due to the slow nature of sound system drift, researchers did not conduct sound calibration between individual participants.

3.5 Data Collection Sites

The study sample was collected from up to five data collection sites; the NADS, Clemson University, Texas A&M Transportation Institute, University of Washington, and the engineering firm, Leidos. The selected sites represent the diverse driver population across the United States and provide geographic diversity (bi-coastal, southern, and mid-west regions of the United States) and a range of population densities and socioeconomic factors from which to draw a representative sample.

The NADS provided experimental protocol material to all data collection sites for submission and approval by their individual institutional review boards (IRBs). The NADS provided paper versions and access to online versions of all surveys, participant training materials, scenario descriptions, and documentation on the online survey service and associated security information for submission to individual IRBs for approval.

The NADS developed and provided additional materials not subject to IRB review and approval that supported collection of consistent data across all data collection sites. These materials included checklists to verify simulator settings associated with experimental conditions, such as confirmation that sound levels of auditory alerts matched specified experimental levels, participant accountability records, and checklists for individual participant experimental drives, to ensure consistent notation of any issues that may explain variations in collected data.

3.6 Sampling and Participant Recruitment

Participants were healthy men and women 25 to 55 years old with valid driver licenses. This was determined through a telephone screening questionnaire (Appendix A). To facilitate a distribution across the overall age range, we separated the participants into two age groups, 25-to-40 and 41-to-55 (Najm, Stearns, Howarth, Koopmann, & Hitz, 2006). Each age group had an equal number of male and female drivers. Although the sample of participants may not represent the general driving population, these participants do represent those drivers who are the most likely to use CW systems (Najm, Stearns, Howarth, Koopmann, & Hitz, 2006; Antin et al., 2011; Lerner et al., 2011). The age and gender groups are comparable to those used in related studies; for example, the CWIM project also selected a similar age group of 25 to 59 (Lerner et al., 2011).

The research team attempted to recruit a racially and ethnically diverse sample. Each site determined compensation amounts to attract participants in their area without being coercive. Based on previous experience conducting simulator studies, we determined the following inclusion and exclusion criteria for inclusion in the study.

- Possess a valid U.S. driver's license
- Licensed driver for 2 or more years

- Drive at least 3,500 miles per year for the past 2 years
- Drive at least once per week
- Restrictions on driver's license limited to corrective lenses
- Report normal or corrected to normal vision
- Report normal or corrected to normal hearing
- Have experience engaging in distracting activities while driving, including talking on a cell phone, sending or receiving text messages, sending or receiving emails, eating, or changing compact discs
- 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
- No participation in a driving simulator study in the past 6 months
- Be a native English speaker
- Not identify as having a high likelihood of experiencing simulator sickness

Each site used a combination of the following recruitment methods: advertisements, flyers, and e-mails. Researchers first screened interested individuals who contacted the research team via telephone. Individuals who were willing to participate and met all inclusion criteria enrolled in the study.

3.7 Independent Variables

The study had a between-subjects design given that each driver could only experience one crash scenario during any one study. The independent variables were alert characteristics (fundamental frequency, duty cycle, tempo) and urgency levels (five levels: low-low, medium-low, medium, medium-high, high-high) which are presented in section 3.1. We counterbalanced the age levels and gender in each experimental block.

3.8 Dependent Measures

The research team combined all of the scenarios, event, and driver performance data with the questionnaire data to address each research question. We synchronized the simulator data and survey datasets over all five collection sites and verified the completeness of the data, as well as its validity, prior to analysis. Variables used for analysis include the following.

- Event data – event information of specific scenarios generated in the driving simulator environment

  a. Relevant driving scenario

  b. Alert characteristic: three alert characteristics for auditory warnings

  c. Urgency level: five levels of urgency for alerts (low-low, medium-low, medium, medium-high, and high-high)

  d. Speed at alert: Speed of the host vehicle when the alert was triggered

  e. Event outcome: Contact between the participant vehicle and lead vehicle (incursion vehicle in IMA & LTAP scenarios)

f. Headway at alert: headway between host vehicle and lead vehicle when the alert was triggered

- Driver performance data – longitudinal measures, as well as drivers' responses, obtained from driving simulator

  a. Initial driving state: driver’s pre-alert driving state (speed, accelerator/brake/steer state)

  b. Type of response: accelerate only, brake only, steer only, compound

  c. Throttle release reaction time: time after alert until driver’s release of throttle

  d. Brake reaction time: time after alert until driver’s depression of brake pedal

  e. Accelerating reaction time: time after alert until driver’s depression of accelerator

  f. Steering reaction time: time after alert until turning steering

  g. Max deceleration: maximum deceleration rate

- Questionnaire data – obtained from the demographic questionnaire and pre- and post-intervention questionnaires for drivers

  a. Demographics and driving history (age and years of driving, gender, race/ethnicity, education level, driving experience, vehicle type, crash history, etc.)

  b. Drivers’ perception and attitudes towards the effectiveness of alerts including noticeability, effectiveness, and understandability of alert

3.9 Experimental Procedure

Researchers first screened potential participants via telephone to determine if they qualified for the study. If the participant met all inclusion criteria and agreed to participate in this study, the research team scheduled a study appointment time. Once the participants arrived at their study appointment, the experimenter then verbally reviewed the informed consent form (ICF) and obtained participants’ written consent. All participants received a copy of the signed ICF at the end of their visit. Participants showed their driver’s licenses to confirm that they were valid, filled out payment forms, and completed a questionnaire that covered some general questions about their driving, demographics, vision, hearing, and motion sickness related to use of a driving simulator.

The participants received training on the driving simulator, which included an overview of the simulator and a description of the in-vehicle task (rear-end with FCW only) from the experimenter. Researchers provided participants with no training on the in-vehicle system or alert in order to capture natural data from participants who had not experienced similar systems in vehicles nor were participants informed there would be a collision-imminent situation. This is consistent with the procedures from the CWIM program (Lerner et al., 2015). Instead, participants were told the purpose of the study was to examine differences in drivers across the United States. Then participants completed the study drive, which lasted approximately ten minutes. Immediately following the end of the experimental drive, participants completed a wellness survey on which they reported any symptoms associated with simulator sickness. If the symptoms reported were moderate or severe, we provided the participant with a beverage and a snack and asked them to rest until the symptoms subsided (typically within 10 to 20 minutes). Researchers replaced participants reporting moderate or severe simulator sickness symptoms.

After the simulator procedures were completed, participants filled out short questionnaires about their perceptions of the alerts and on the realism of the simulator. A researcher then provided a debriefing statement that explained the purpose of the research. A member of the research team completed participants' payment form and the study visit was completed.

3.10 Data Handling

3.10.1 Data Transfer

In order to ensure data quality and consistency in data reduction, each site transferred all raw data to the NADS. Researchers used the NADS UI Qualtrics account to collect survey data and NADS staff directly downloaded it for analysis and back-up. NADS Mercury, an in-house application designed to securely transfer simulator data between individual simulators to the NADS using end-to-end encryption (E2EE) transferred simulator data files to the NADS on a scheduled nightly basis. The application created file "thumbprints" before and after transfer, ensuring the validity of transferred data. It emailed receipts to site administrators and NADS staff each time a duplication process was initiated, detailing files transferred or if any file transfer failures. It completed failed file transfers during the next duplication process, which was typically the next night. The NADS defined unique logins for each study site using strong, system-generated passwords. The Leidos site was the only exception to this otherwise internet-enabled process. Since Leidos did not have an internet connection capable of handling large file transfers, we used an offline version of the same Mercury client/server system using external USB hard drives. The USB Mercury system used the same thumbprint and receipt system to ensure file validity.

Following receipt of the data, the NADS conducted initial verification procedures to ensure all data files we received were intact. The NADS reported any issues with data files to the data collection site and the site investigated the cause to resolve any issues. Project-related files stored at the NADS are mandated to have at least two copies of any file recorded. This includes an on-site copy, as well as a duplicate of the original which is stored at a secure (physically and digitally) off-site location. At the conclusion of a study, the NADS generates two offline copies of the final data: one that stays in a physically secured area at the NADS and another that is sent to a physically secure off-site data storage locker.

3.10.2 Data Verification

Verification occurred for both data files received and for specific measures within the reduced data. NADS staff compared incoming data files to participant accountability information provided by each site. We compared the assigned participant number and expected experimental conditions to match the accountability and experimental condition matrix. We used this to confirm the correct simulator drive usage for each participant. We also confirmed that the experimental conditions within the simulator data file for each participant matched the experimental condition matrix. This provided confirmation that the experimental conditions were correct within the simulator drive. We next confirmed event timing and conditions in the reduced data file.

3.11 Data Variables

For all the scenarios, we combined event and driver performance data with the questionnaire data to address each research question. We synchronized the simulator data and survey datasets over all five collection sites and the completeness of the data will be verified prior to analysis. Variables used for analysis include the following.

- Event data – event information of specific scenarios that will be generated in the driving simulator environment

  a. Relevant driving scenario
  b. Alert characteristic: six alert characteristics for auditory warnings (including baseline, i.e., no warnings)
  c. Urgency level: five levels of urgency for alerts (low-low, low-medium, medium, medium-high, and high-high)
  d. Speed at alert: speed of the host vehicle when the alert was triggered
  e. Crash status: contact between the host vehicle and lead vehicle (incursion vehicle in IMA and LTAP scenarios)
  f. Headway at alert: headway between host vehicle and lead vehicle when the alert was triggered

- Driver performance data – longitudinal measures, as well as drivers' response behavior, obtained from driving simulator

  a. Initial driving state: driver's pre-alert driving state (e.g., speed, accelerator/brake/steer state)
  b. Type of response: accelerate only, brake only, steer only, compound
  c. Throttle release reaction time: time after alert until driver's release of throttle
  d. Brake reaction time: time after alert until driver's depression of brake pedal
  e. Accelerator reaction time: time after alert until driver's depression of accelerator
  f. Steering reaction time: time after alert until turning steering
  g. Max deceleration: maximum deceleration rate

- Questionnaire data – obtained from the demographic questionnaire and pre- and post-intervention questionnaires for drivers

  a. Demographics and driving history (age/years of driving, gender, race/ethnicity, education level, driving experience, vehicle type, crash history, etc.)
  b. Drivers' perception and attitudes towards the effectiveness of alerts

4 DATA ANALYSIS AND STATISTICAL MODELING

4.1 Occurrence of Crash

Crash occurrence was analyzed to gain insights on drivers' ability to understand and respond to different alert characteristics. The crash frequencies and crash rates were evaluated for different alert characteristics with multiple urgency levels for each scenario. The purpose of this analysis is to examine if there exists any particular urgency level greatly affecting crash rate.

4.2 Driver Response Data

The alert characteristics were expected to impact drivers' response to the alert. Then drivers' reaction to the alert and the conditions of the near-collision scenario (e.g., the urgency of the event or whether the driver was distracted) were studied to determine if they would impact the occurrence of crash. Drivers' responses to alerts can be classified into two perspectives:

1. How quickly a driver reacts to the alert (i.e., reaction time)
2. To what extent the driver reacts to the near-collision scenario (i.e., reaction intensity)

In this study, braking maneuvers dominated as the majority of crash avoidance maneuvers. Hence, we used drivers' throttle release reaction time and brake reaction time to measure how quickly drivers responded to the alert. We used the drivers' maximum deceleration observed in the entire crash avoidance process as a measure of reaction intensity.

For all the analyses, we set the medium (MM) level as the unique baseline for comparison across all the alert characteristics and scenarios.

We used analysis of variance (ANOVA) as the primary statistical method to examine the difference in driving performance across different treatment groups. For this study, each alert characteristic (e.g., frequency, tempo, and duty cycle) was examined separately in a one-way ANOVA.

We also examined the differences among treatment groups (or alert characteristics) using separate linear regression models. In these regressions, the dependent variable was one of the reaction times and reaction intensity of participant. The independent variables considered for each alert characteristic included urgency levels, scenarios, age, gender, and testing location.

Both the ANOVA and multiple linear regression are based on regression techniques (Grace-Martin, 2013). The outcomes of the one-way ANOVA did not show any differences in treatment conditions. However, the overall difference in treatment groups was not the primary goal of this study. We therefore used the MM level as the reference group in the multiple linear regression model, which provides a more useful comparison and is in line with the project aim to identify the relatively best and worst alert urgency level.

4.3 Subjective Data

We derived the subjective data from surveys with seven outcomes indicating subject's agreement levels with the statement evaluated. These questions investigated drivers' feedback on the alert from three different perspectives: noticeability, effectiveness, and understandability. The noticeability measures how easy the alert attracted a driver's attention. The effectiveness measured how well the alert helped drivers to avoid a collision. The understandability measured whether the alert was easy to interpret and understand.

We analyzed the subjective data using bubble charts. The size of each bubble represents the frequency of rating for a particular rating score (1-7) and an urgency level. The bubble charts provided visualization for three alert characteristics in each of the three scenarios (FCW, IMA, and LTAP). The chart also displays the mean value for rating scores for reference.

In order to validate the consistency with reaction data, we made additional line charts to compare the results of subjective data with reaction data. Similarly, we made this visualization for each of the three scenarios and three alert characteristics.

4.4 Treating Missing and Invalid Data

In order to evaluate the effectiveness of the alert based on the event outcome (crash), as well as the driver's reaction data after receiving the alerts, each driver should have a valid pre-crash scenario and responses after the alerts. We excluded some missing or invalid data from the analysis of outcome for the following reasons.

- Excessive speeding drivers: samples with speed beyond 60 mph when receiving alerts were removed for all analyses
- No threat with incursion (or lead) vehicle: samples with infinite minimum time-to-collision (TTC) were removed for all analyses
- Drivers react before alert: some participants responded before an alert (e.g., throttle release, brake, steering and throttle press), with no response detected after alert. These drivers were removed for all analyses
- Drivers without valid reaction measures: participants with no valid throttle release and brake reaction after alert but with other kinds of reactions (steering or throttle press) were removed only for reaction time analysis but kept for subjective analysis

5 FORWARD CRASH WARNING STUDY

5.1 Specific Method

5.1.1 Driving Scenarios

Once comfortably seated in the simulator and prior to beginning the drive, participants practiced the in-vehicle distraction task, described in section 5.1.1.1. The protocol employed a distraction task to allow the rear-end collision event to be orchestrated without eliciting a response from the driver prior to the presentation of the FCW alert.

The drive began with the participant's vehicle parked on the side of the road and the participant was instructed to begin driving. Once on the roadway, the simulator instructed the participant to steer left and right in their lane to become familiar with steering in the simulator. Participants encountered a stop sign controlled intersection several seconds into the drive to allow them to become familiar with braking in the simulator. At a point early in the drive following the stop sign controlled intersection, a lead vehicle turned onto the roadway at an intersection and remained present throughout the drive. The lead vehicle maintained 2.2-second headway from the participant's vehicle. The posted speed limit was 55 mph. The participant encountered intersections at regular intervals where a lead vehicle decelerating event could be orchestrated within a context typical of that type of event. Following this practice portion of the drive, participants periodically interacted with the distraction task. The first four instances of the task, one prior to beginning the drive and three during the drive, allowed participants to become familiar with the task prior to the final instance. During the final instance, the participant looked away from the forward view and the lead vehicle decelerated at 0.7 g to a stop near an intersection as if it intended to make a left turn. However, the lead vehicle did not employ turn signals to avoid alerting the driver to potential lead vehicle braking prior to the event. Figure 3 provides a summary of the timing of the FCW event with the 5.8 average time of collision from participants who experienced collisions. Figure 4 provides a visualization of the driving scene at the point of the FCW warning.

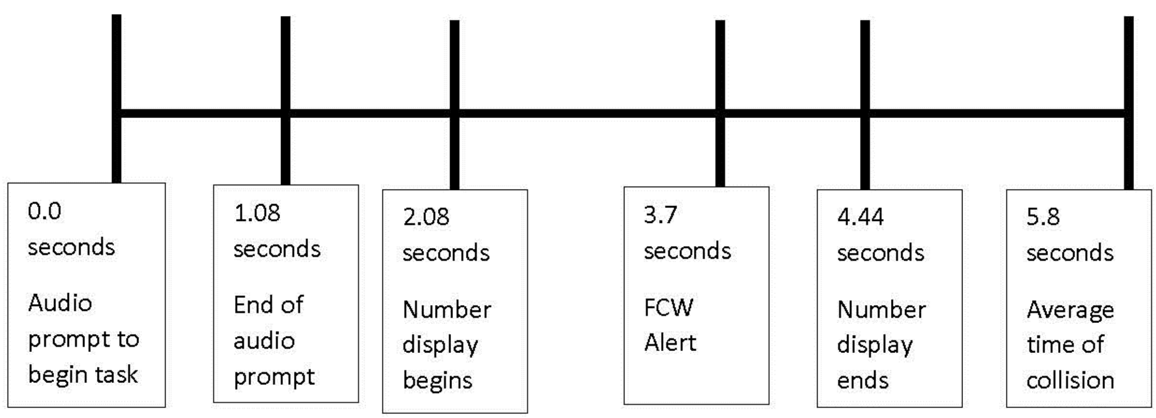

Figure 3 Timing of rear-end crash with FCW event

Figure 4 Rear-end crash scenario at point when FCW alert is issued

5.1.1.1 Distraction Task for Rear-End Crash FCW Scenario

Engaging the participant in an in-vehicle task that draws their attention, particularly their visual attention, away from the forward roadway allows the orchestration of a rear-end collision without the participant reacting to the event prior to the presentation of an FCW alert. If a participant responds to the event prior to the alert, then the response cannot be attributed to the alert. Since participants encountered only one rear-end collision event to minimize their anticipation of subsequent similar crash scenarios, it was critical that participants respond to the alert rather than before.

Recent work at the NADS for the CWIM program showed that a number recall task was the most effective of those tested in providing sufficient time for rear-end collision events to be triggered without the participant looking forward early (Lerner et al., 2015). The participants experienced the task consistent with the FCW evaluation protocol specifications (Brown & Marshall, 2014; Lerner et al., 2015). A small screen located between 90 and 110 degrees to the right of the participant's forward-facing position at the approximate height of the driver's head displayed the task. The position varied slightly based on the driver's preferred seat position. One second after receiving the instruction to begin the task, the display presented five random single-digit numbers for 472 ms each for a total task duration of 2.36 seconds. The numbers were 2.5 inches in height and 1.5 inches in width with a font similar to DS-Digital and a RGB color of 0.7, 0,0. The participant repeated the numbers aloud after all five had been displayed in the correct order to the experimenter following each instance of the task (Forkenbrock, Heitz, et al., 2011). Figure 5 shows an example of the task in the 1/4-cab miniSim. We only used the distraction task in the rear-end collision with FCW scenario.

(a) (b)

Figure 5 Number recall display

5.1.2 Participants

Table 3 provides the distribution of gender and age for the FCW study. For the three varying alert characteristics (fundamental frequency, duty cycle, tempo), the characteristic being tested is the only condition to be tested. All other characteristics were held at the “medium” level. This design results in a total of 40 unique participants per cell in the rear-end with FCW scenario. There were a total of 520 participants from the five sites for the rear-end with FCW scenario. Table 4 provides the distribution of participants across experimental conditions for each scenario.

Table 3 Participant Age and Gender at Each Data Collection Site for the Rear-End With FCW Scenario

Age group	Male	Female	Total
25-40	N=26	N=26	52
41-55	N=26	N=26	52
Total	52	52	104

Table 4 Participants per Experimental Condition for the Rear-End With FCW Scenario

	Low-Low (LL)	Medium-Low (ML)	Medium (MM)	Medium-High (MH)	High-High (HH)
Fundamental Frequency	40 total 8 per site	40 total 8 per site	40 total 8 per site	40 total 8 per site	40 total 8 per site
Duty Cycle (% time present)	40 total 8 per site	40 total 8 per site		40 total 8 per site	40 total 8 per site
Tempo Pulses/Second	40 total 8 per site	40 total 8 per site		40 total 8 per site	40 total 8 per site
	520 Total participants across five sites 104 participants per site				

5.2 Results

5.2.1 Outcome

When considering the outcome of the FCW scenario, the rate of crashes varied by experimental condition (see Table 5). For fundamental frequency, the medium-low level produced the fewest crashes. For duty cycle, the medium-low and medium-high levels produced the fewest crashes. For tempo, the low-low condition produced the fewest crashes.

Table 5 FCW Crash Frequency

Condition	**Urgency Level**				
	Low-Low (LL)	Medium-Low (ML)	Medium (MM)	Medium -High (MH)	High-High (HH)
Fundamental Frequency	27 68%	22 55%		29 73%	34 85%
Duty Cycle	30 79%	23 58%	31 77%	23 58%	30 75%
Tempo	26 65%	30 75%		30 75%	28 70%

5.2.2 Driver Performance

Driver response in terms of throttle release time and brake reaction time characterizes driver response to the alerts associated with FCW scenarios. Additionally, maximum deceleration provides a measure of driver response.

5.2.2.1 Throttle Release

When considering the throttle release response for the FCW scenario, fundamental frequency and duty cycle produced significant results. In the following figures, the red dashed line was the mean value within each urgency level. For fundamental frequency, the low-low urgency level produced longer release times compared to the medium urgency level (Figure 6). For duty cycle, the low-low urgency level produced longer release times compared to the medium urgency level (Figure 7). Tempo produced no significant effects.

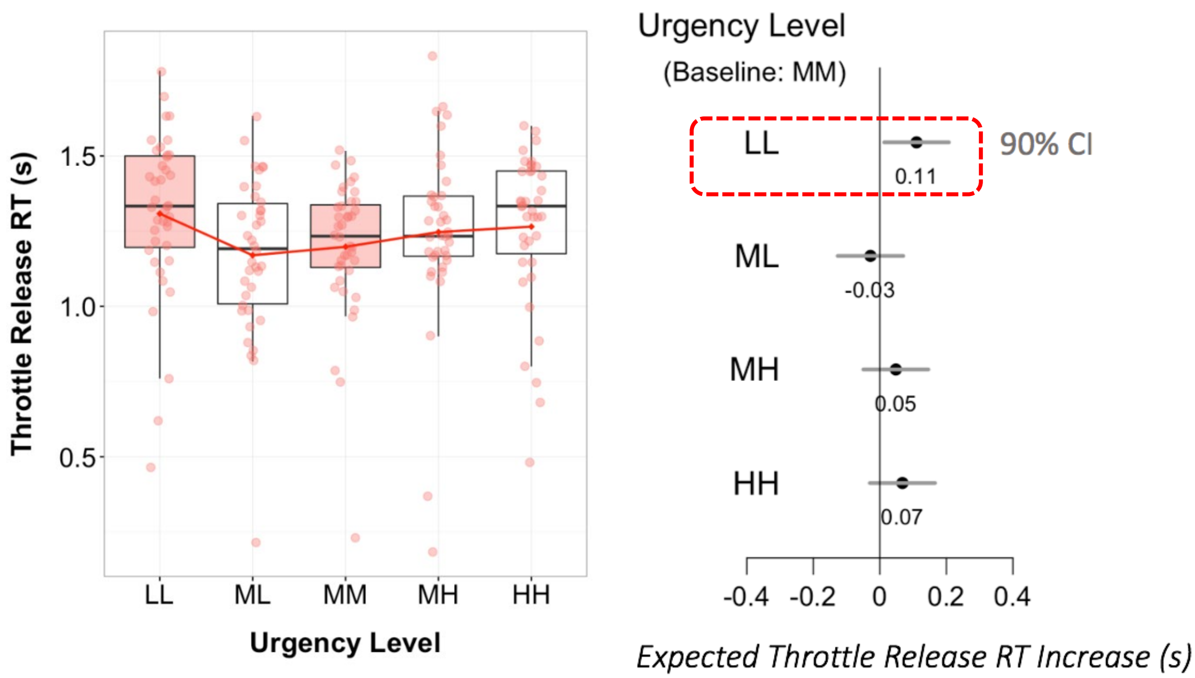

Figure 6 Fundamental frequency throttle release RT– FCW scenario. Box plots (left). Comparisons between medium and other urgency levels with a red box indicating significant differences (right).

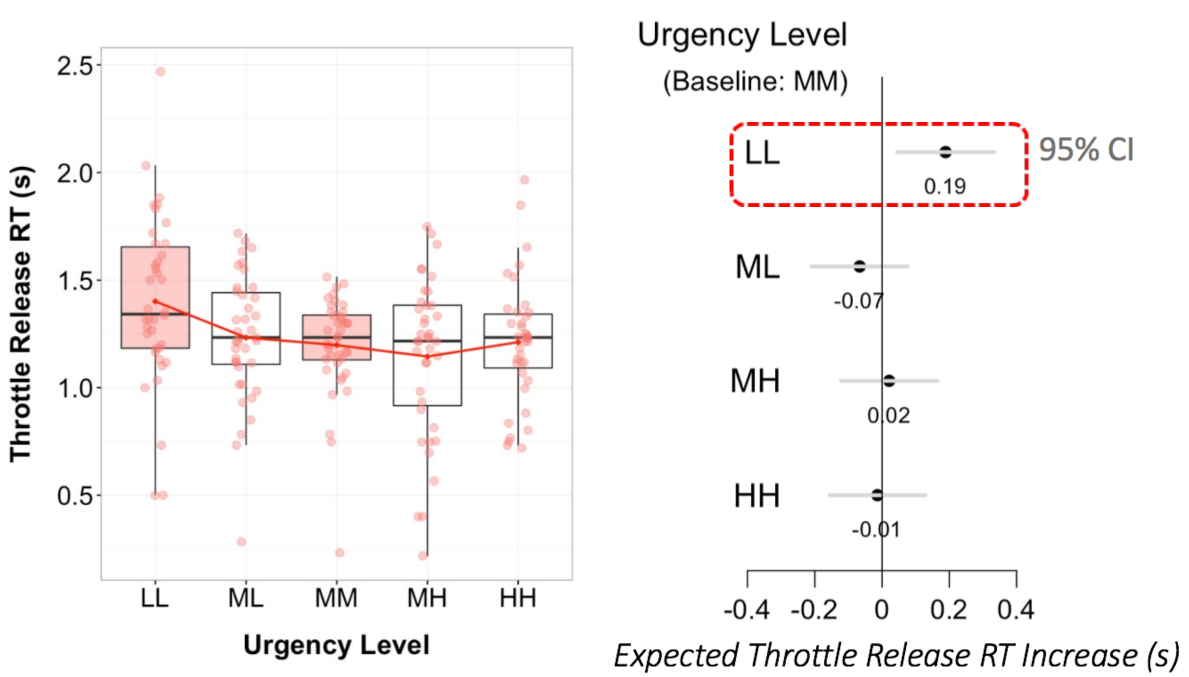

Figure 7 Duty cycle throttle release RT – FCW scenario. Box plots (left). Comparisons between medium and other urgency levels with a red box indicating significant differences (right).

5.2.2.2 Brake Press

When considering the brake press response for the FCW scenario, fundamental frequency and duty cycle provided significant results. For fundamental frequency, the medium-high urgency level produced longer reaction times compared to the medium urgency level (Figure 8). For duty cycle, the low-low urgency level produced longer release times compared to the medium urgency level (Figure 9). Tempo produced no significant effects.

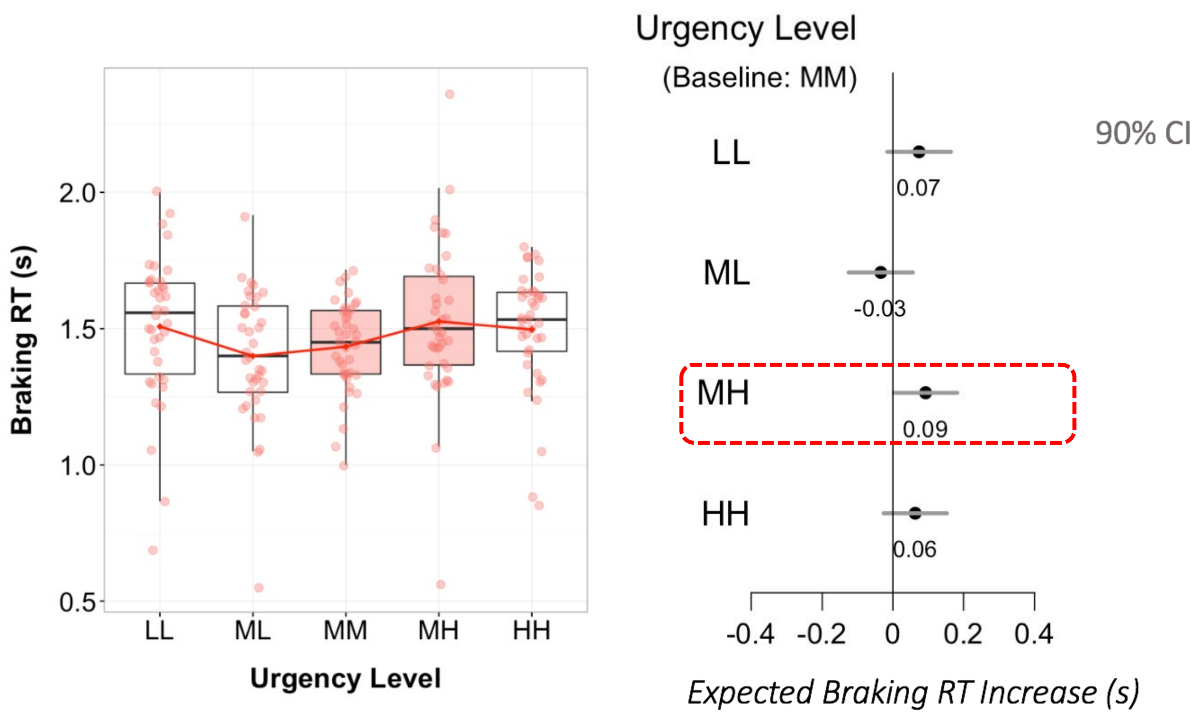

Figure 8 Fundamental frequency brake press RT – FCW scenario. Box plots (left). Comparisons between medium and other urgency levels with a red box indicating significant differences (right).

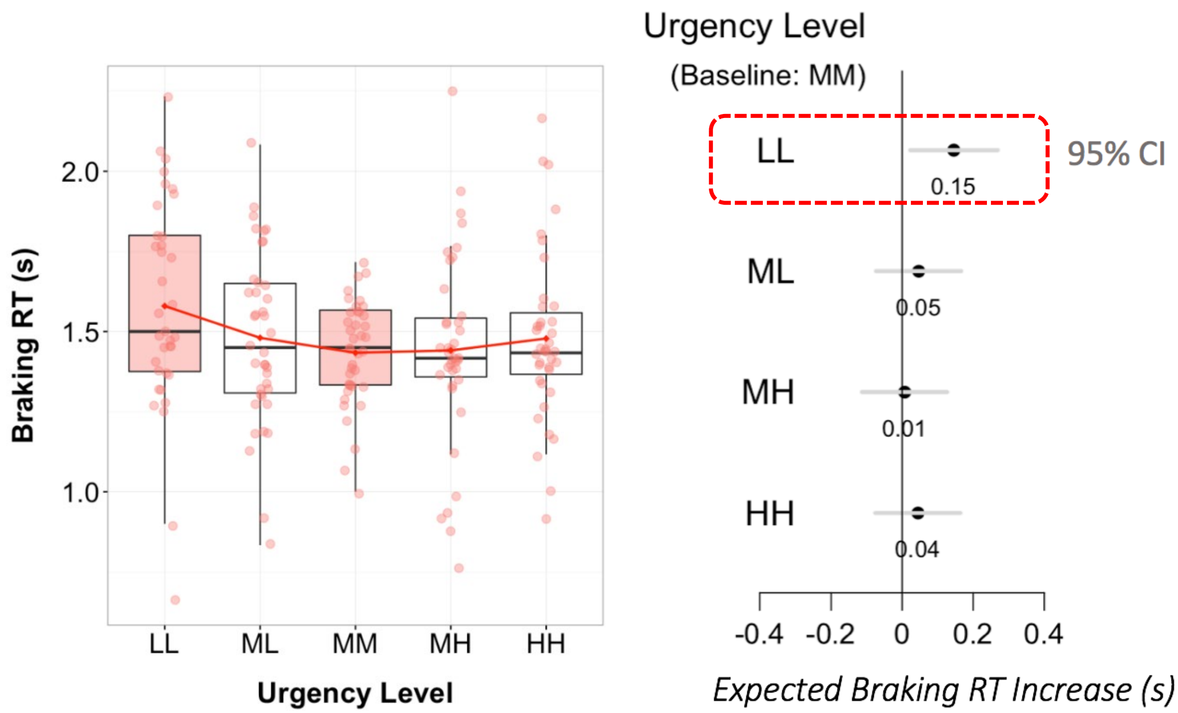

Figure 9 Duty cycle brake press RT – FCW scenario. Box plots (left). Comparisons between medium and other urgency levels with a red box indicating significant differences (right).

5.2.2.3 Max Deceleration

When considering maximum deceleration for the FCW scenario, fundamental frequency, duty cycle and tempo provided significant results. For fundamental frequency, the low-low and medium-high urgency levels produced lower levels of maximum deceleration compared to the medium urgency level (Figure 10). For duty cycle, the low-low and high-high urgency levels produced lower levels of maximum deceleration compared to the medium urgency level (Figure 11). For tempo, the high-high urgency levels produced lower levels of maximum deceleration compared to the medium urgency level (Figure 12).

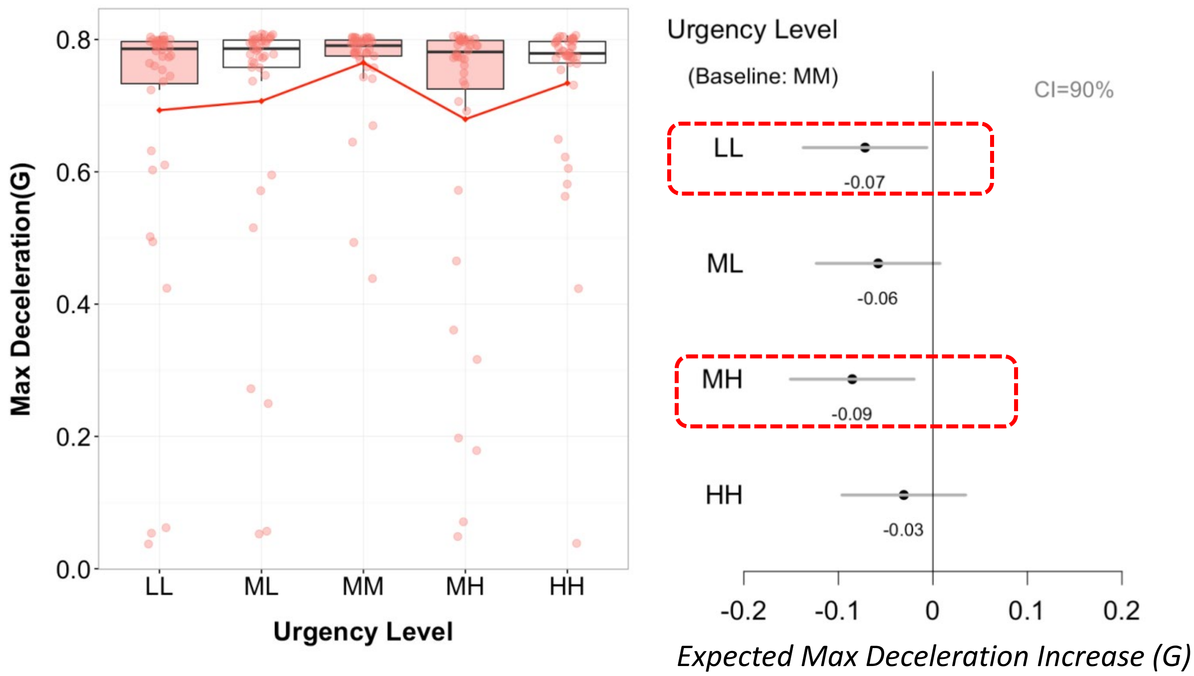

Figure 10 Fundamental frequency max deceleration – FCW scenario. Box plots (left). Comparisons between medium and other urgency levels with a red box indicating significant differences (right).

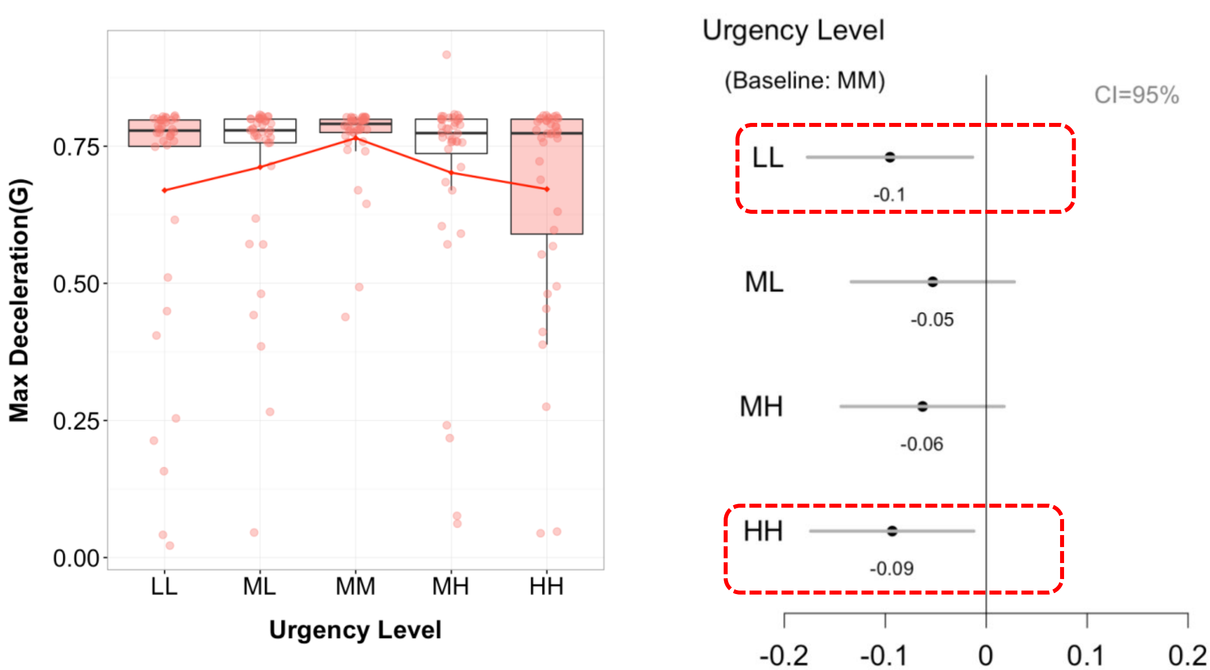

Figure 11 Duty cycle max deceleration – FCW scenario. Box plots (left). Comparisons between medium and other urgency levels with a red box indicating significant differences (right).

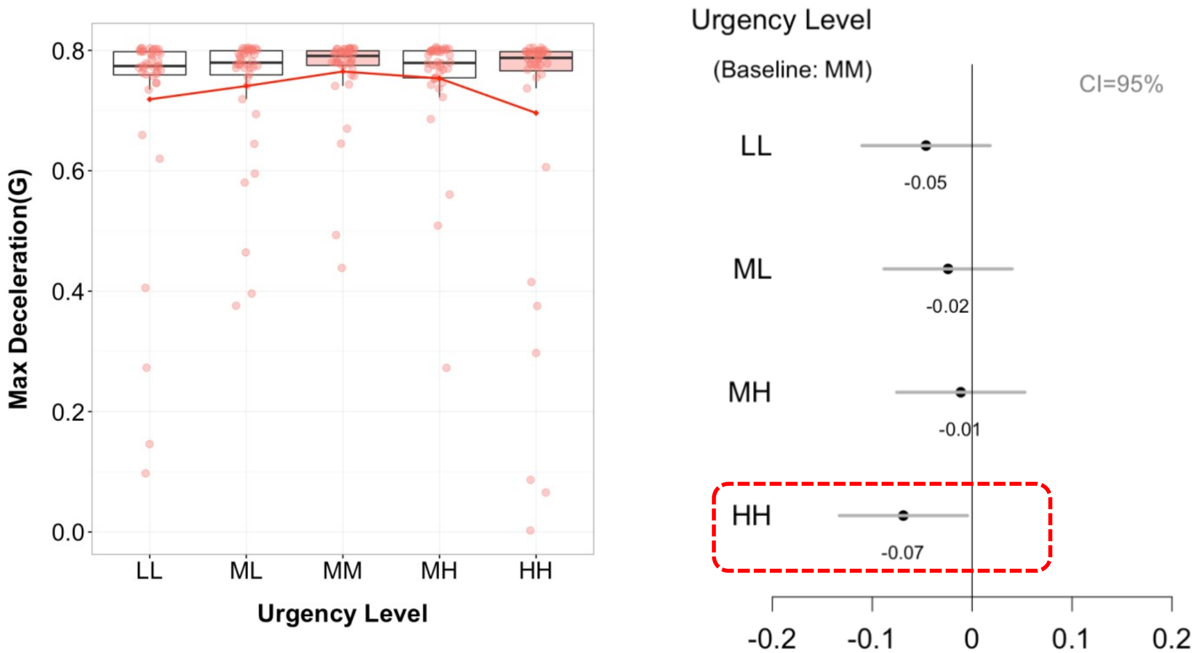

Figure 12 Tempo max deceleration – FCW scenario. Box plots (left). Comparisons between medium and other urgency levels with a red box indicating significant differences (right).

5.2.3 Subjective Data

This section summarizes the results of the subjective evaluation of the auditory alerts for FCW systems. These analyses considered the effects of changes in fundamental frequency, duty cycle, and tempo on the subjective assessment of the alerts. Figure 13 to Figure 15 focus on the noticeability of the alert. As can be seen in the figures, the low-low urgency level of duty cycle produced lower levels of noticeability for the FCW, but fundamental frequency and tempo produced less variability across the range of levels. Figure 16 and Figure 17 focus on the effectiveness of the alert. As can be seen in the figures, there is variability associated with duty cycle. As duty cycle increases from the low-low urgency level perceived effectiveness generally increases before falling off at the high-high urgency level. As with noticeability, fundamental frequency and tempo produced less variability across the range of levels. Figure 18 and Figure 19 focus on the understandability of the alert. As can be seen in the figures, the low-low urgency level of duty cycle produced lower levels of noticeability, but fundamental frequency and tempo produced less variability across the range of levels.

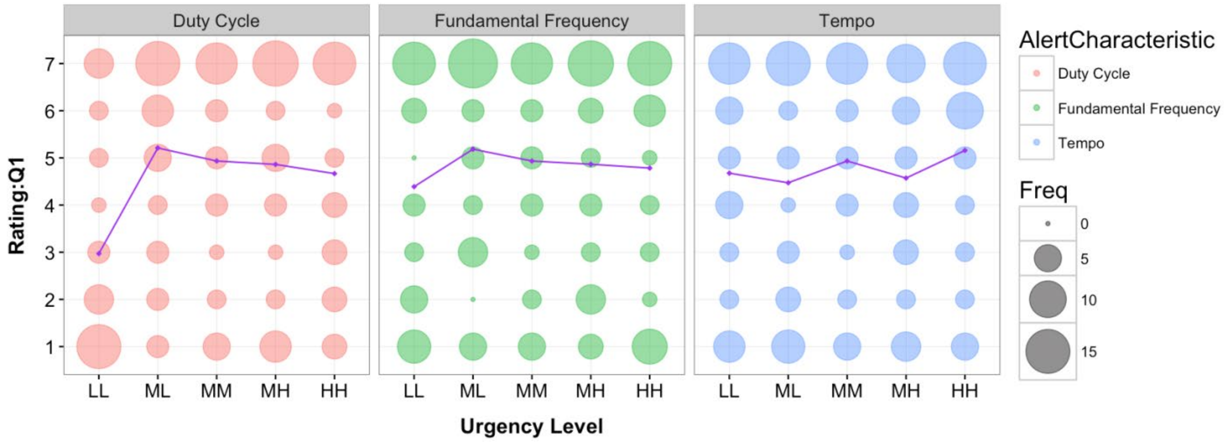

Figure 13 FCW noticeability - The alert: Did not catch my attention (1)…Caught my attention(7)

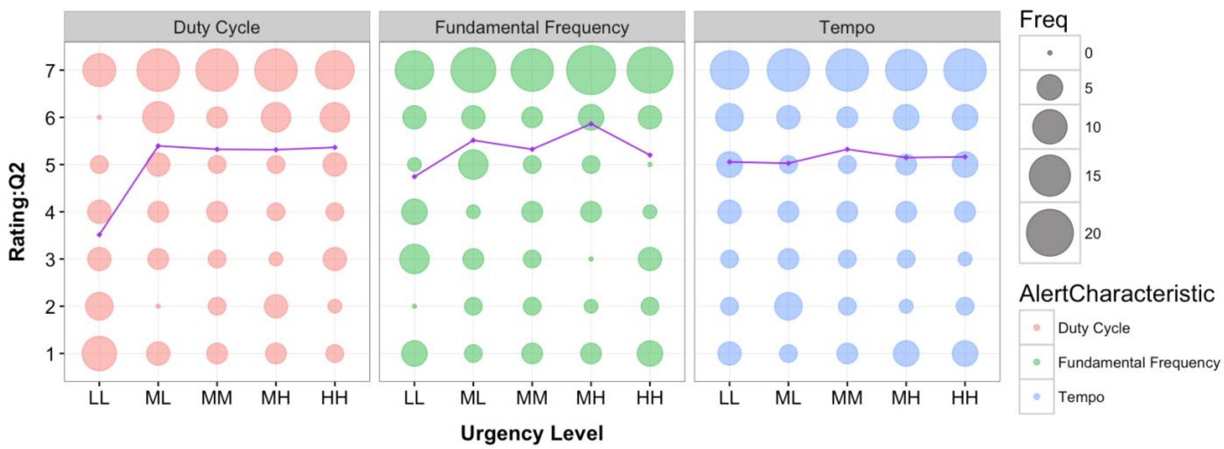

Figure 14 FCW noticeability - The intensity of the alert was: Very difficult(1)…Very easy(7)

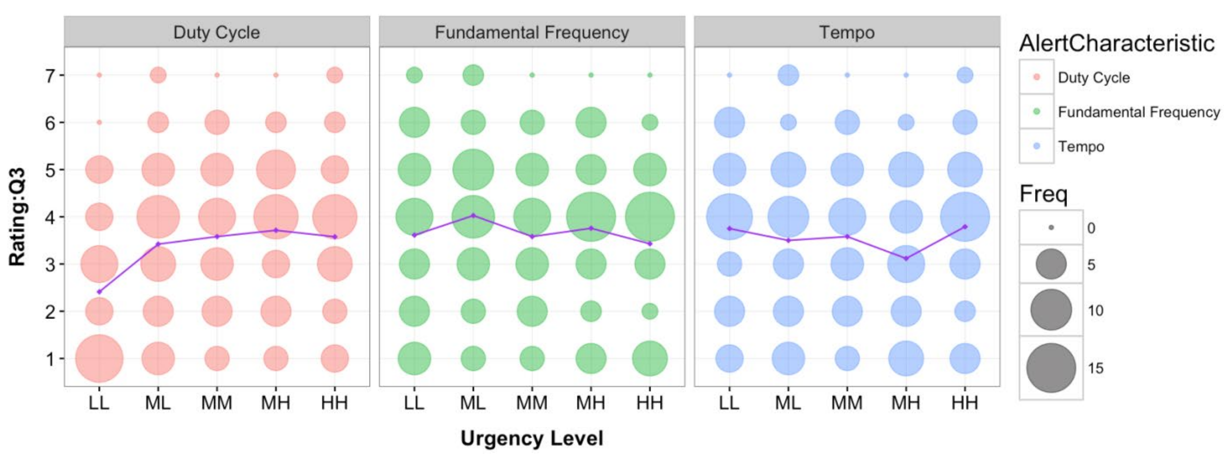

Figure 15 FCW noticeability – The intensity of the alert was: Too weak(1)… Too strong(7)

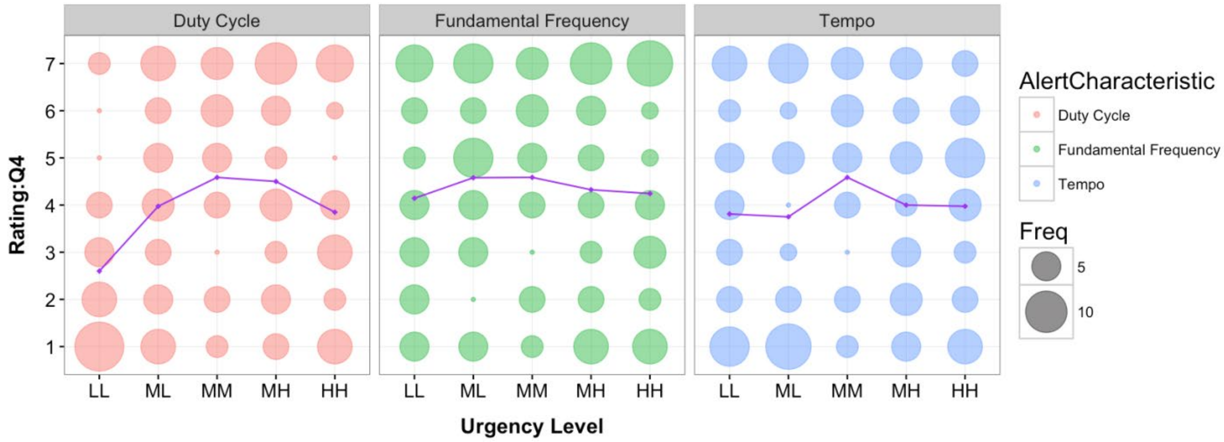

Figure 16 FCW effectiveness – Rate how helpful the collision warning was in identifying vehicles in front of you: Not helpful(1)…Very helpful(7)

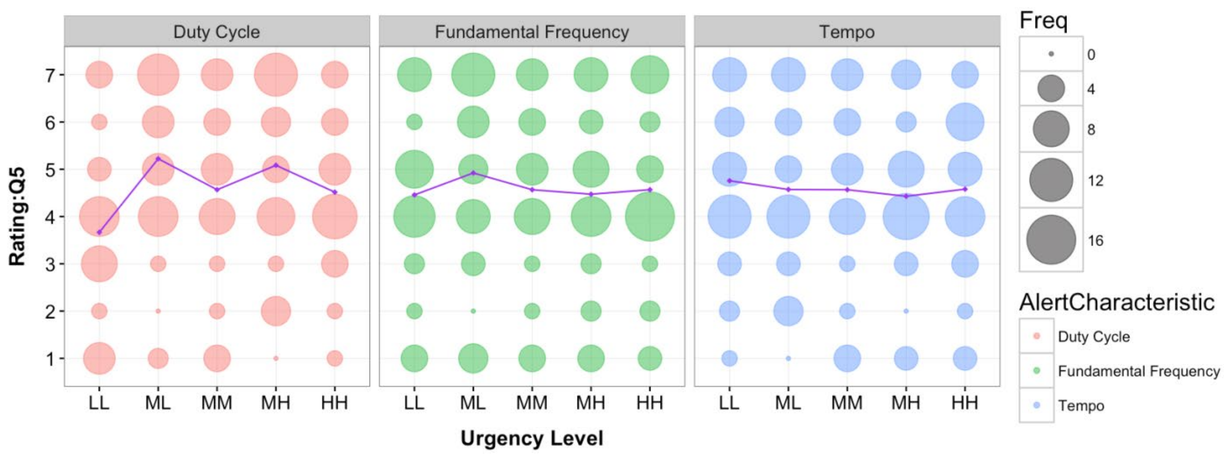

Figure 17 FCW effectiveness – The collision warning affected my driving: Negatively(1)…Positively(7)

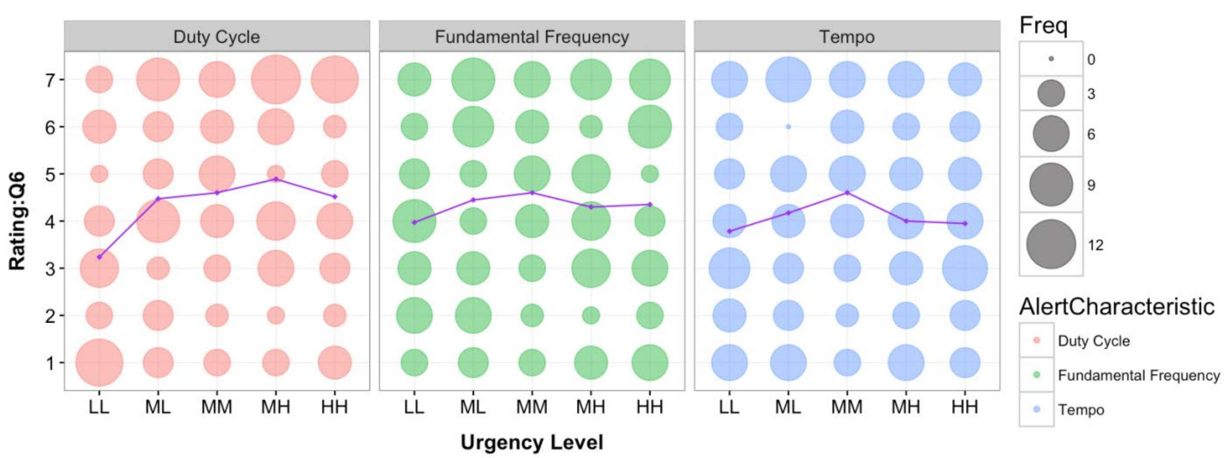

Figure 18 FCW understandability – My ability to interpret the information presented by the alert was: Very difficult(1)…Very easy(7)

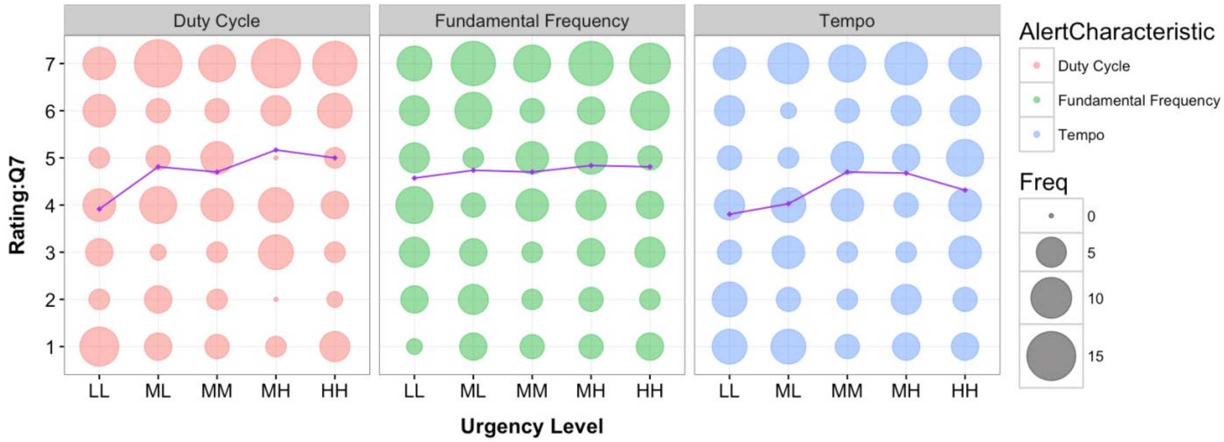

Figure 19 FCW understandability – My ability to understand why the alert was presented was: Very difficult(1)…Very easy(7)

5.2.4 Differences among Sites

Data collection occurred at five sites: Austin, Texas, Clemson, South Carolina, Iowa City, Iowa, Seattle, Washington, and Washington, District of Columbia. These sites were selected given that differences may exist across different geographical regions; this is in addition to differences in response to the alert characteristics. It is important to note that every attempt was made to standardize data collection procedures. However, there were noted differences in the communication provided by the researchers at the Leidos site that may have impacted the outcome.

5.2.4.1 Outcome of Crash Event

The crash frequency and crash rate varied by data collection sites for the FCW scenario (see Table 6). Compared to the other four sites, Washington, District of Columbia. (Leidos) had significantly fewer crashes and a lower crash rate.

Table 6 Crash Frequency and Rate among Data Collection Sites – FCW scenario

	Data Collection Site				
	Austin (TTI)	Clemson (Clemson U.)	Iowa City (NADS)	Seattle (UW)	Washington (Leidos)
Crash Frequency & Crash Rate	81 (77.9%)	75 (72.1%)	80 (76.9%)	74 (71.2%)	53 (52.0%)

5.2.4.2 Driver performance

There appeared to be differences among data collection sites for the FCW throttle release reaction time but they were not statistically significant (Figure 20). Compared to the other four sites, participants from Washington, District of Columbia, (Leidos) seemed to release the throttle more slowly, on average.

There were no significant differences among data collection sites in terms of throttle release reaction time and maximum deceleration.

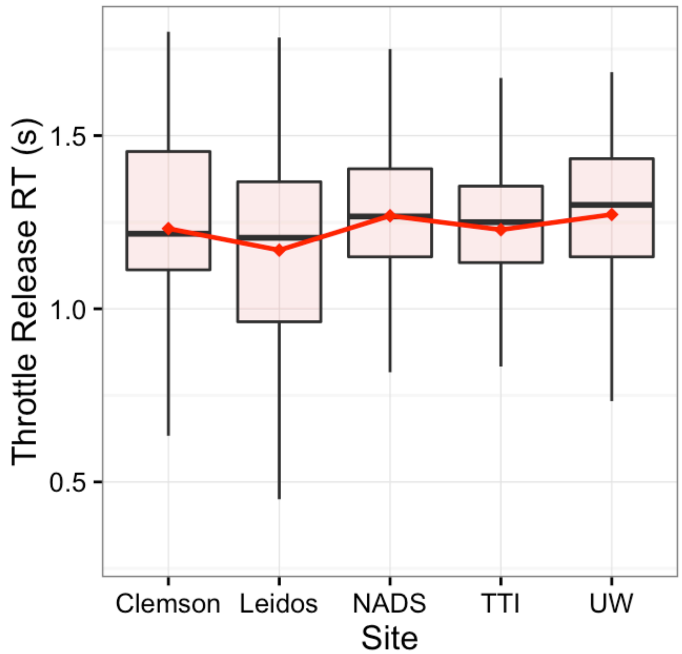

Figure 20 Throttle release RT among data collection sites – FCW scenario

6 INTERSECTION MOVEMENT ASSIST STUDY

6.1 Specific Method

6.1.1 Driving Scenario

Prior to the drive, a researcher instructed participants to follow the directional signs to Shelby. Once comfortably seated in the simulator they began their drive. The drive began with the participant's vehicle parked on the side of the road and the participant was instructed to begin driving. Once on the roadway, the simulator instructed the participant to steer left and right in their lane to become familiar with steering in the simulator. The posted speed limit was 45 mph. The participant encountered intersections at regular intervals preceded by directional signs to Shelby indicating whether participants should turn left, right, or continue straight. A subset of the intersections contained traffic signals. All traffic signals were green for the participant throughout the drive. Approximately ten minutes into the drive, the participant passed a directional sign indicating Shelby was ahead and then approached a signalized intersection with a green light. A heavy truck was on the shoulder of the crossroad to the left of the intersection blocking the driver's line of sight. The simulator created the incursion vehicle as cross traffic from the left at the same speed the participant was traveling. As the participant approached the intersection, the connected vehicle IMA alert triggered before the incursion vehicle was visible to the driver. Figure 21 provides a summary of the timing of the IMA event. Figure 22 provides a visualization of the driving scene at the time of the warning.

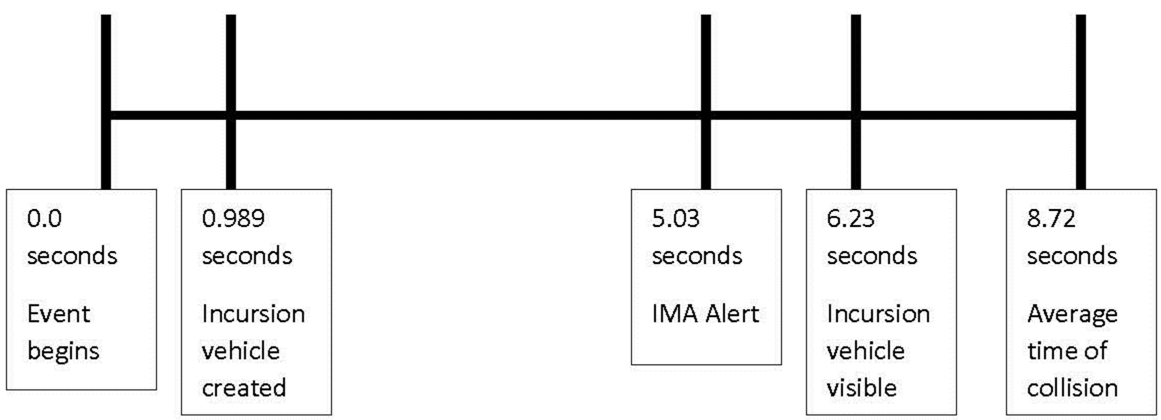

Figure 21 Timing of junction crossing with IMA event

Figure 22 Junction crossing scenario at point IMA is issued

The distraction task was not necessary to ensure the driver was responding to the alert rather than the orchestration of the event as was the case in the rear-end collision scenario. The IMA warning was representative of a V2V system capable of alerting drivers to the presence of a threat before it is visible. The incursion vehicle was not visible to the driver until after the alert.

6.1.2 Participants

Table 7 provides the distribution of gender and age for the IMA study. For the three varying alert characteristics (fundamental frequency, duty cycle, tempo), the characteristic being tested is the only condition to be tested. All other characteristics were held at the "medium" level. This design results in a total of 16 unique participants per cell in the IMA scenario. There were a total of 416 participants from four sites for the junction crossing with IMA. Table 8 provides the distribution of participants across experimental conditions for each scenario.

Table 7 Participant Age and Gender at Each Data Collection Site for the Junction Crossing with IMA and LATP Scenarios

Age group	Male	Female	Total
25-40	N=13	N=13	26
41-55	N=13	N=13	26
Total	26	26	52

Table 8 Participants per Experimental Condition for the Rear-End with IMA Scenario

	Low-Low (LL)	Medium-Low (ML)	Medium (MM)	Medium-High (MH)	High-High (HH)
Fundamental Frequency	16 total 4 per site	16 total 4 per site		16 total 4 per site	16 total 4 per site
Duty Cycle (% time present)	16 total 4 per site	16 total 4 per site	16 total 4 per site	16 total 4 per site	16 total 4 per site
Tempo Pulses/Second	16 total 4 per site	16 total 4 per site		16 total 4 per site	16 total 4 per site
	208 Total participants across four sites 52 participants per site				

6.2 Results

6.2.1 Outcome

When considering the outcome of the IMA scenario, the rate of crashes varied by experimental condition (see Table 9). For fundamental frequency, the low-low and medium-high level produced the fewest crashes. For duty cycle and tempo, the medium-high levels produced the fewest crashes.

Table 9 IMA Crash Frequency

Condition	**Urgency Level**				
	Low-Low (LL)	Medium-Low (ML)	Medium (MM)	Medium-High (MH)	High-High (HH)
Fundamental Frequency	12 75%	14 88%		12 75%	15 100%
Duty Cycle	15 100%	15 94%	15 100%	14 88%	16 100%
Tempo	16 100%	14 88%		13 81%	15 94%

6.2.2 Driver Performance

Driver response in terms of throttle release time and brake reaction time characterizes driver response to the alerts associated with FCW scenarios. Additionally, maximum deceleration provides a measure of driver response.

6.2.2.1 Throttle Release

When considering the throttle release response for the IMA scenario, fundamental frequency and duty cycle produced significant results. For fundamental frequency, the high-high urgency level produced longer release times compared to the medium urgency level (Figure 23). For duty cycle, the low-low and medium-high urgency levels produced longer release times compared to the medium urgency level (Figure 24). Tempo produced no significant effects.

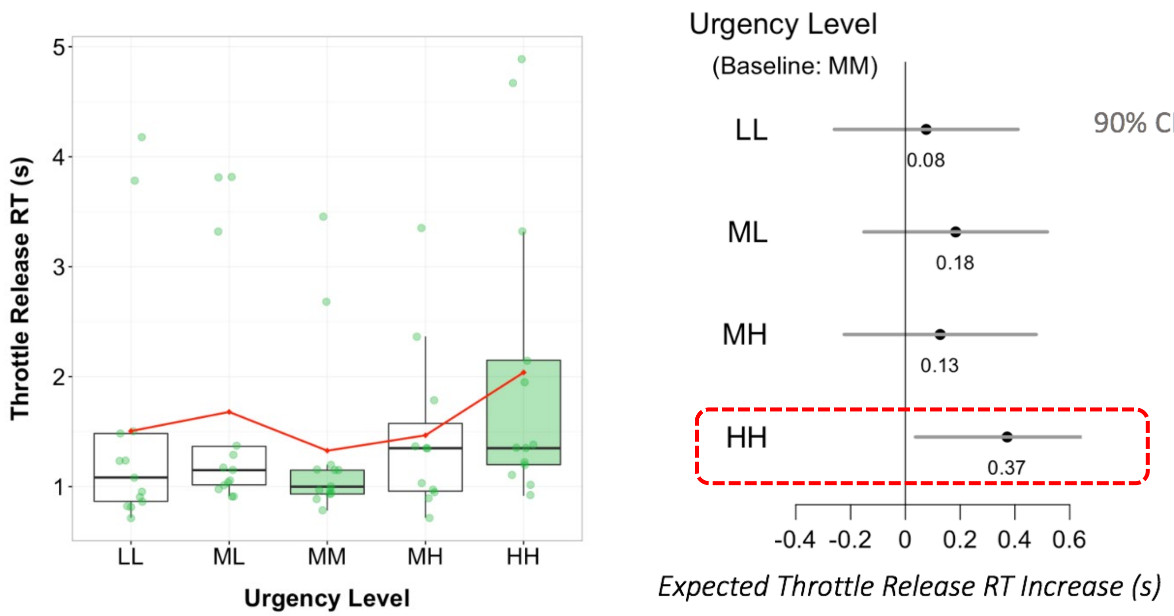

Figure 23 Fundamental frequency throttle release RT – IMA scenario. Box plots (left). Comparisons between medium and other urgency levels with a red box indicating significant differences (right).

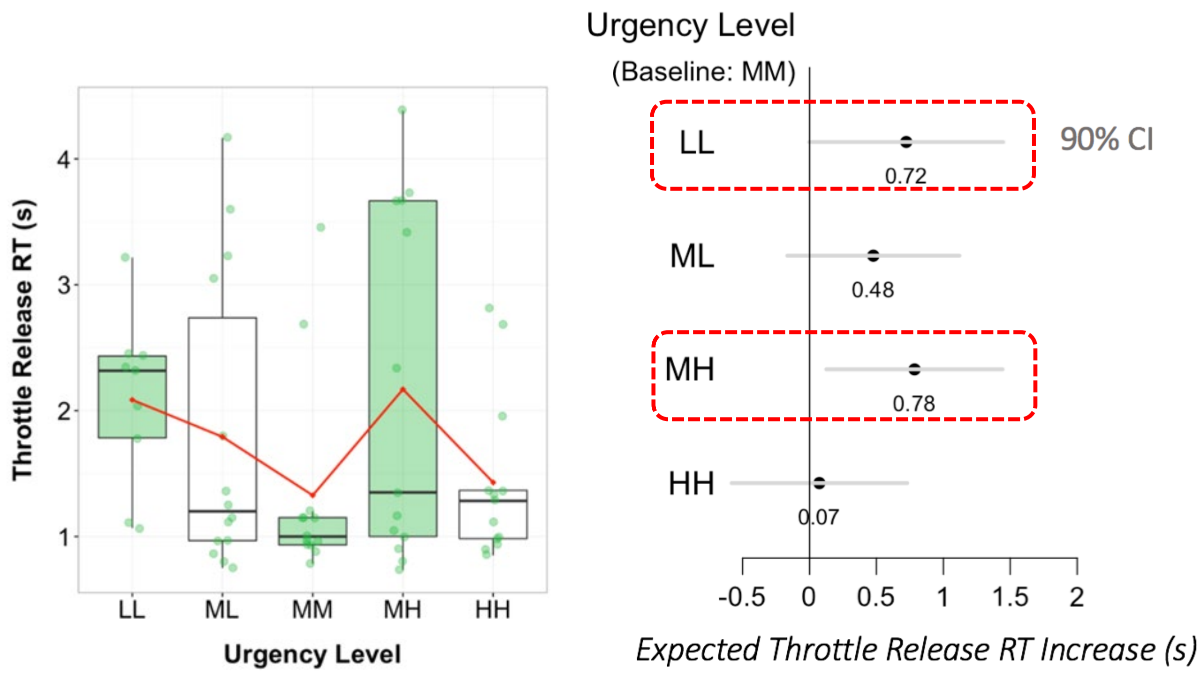

Figure 24 Duty cycle throttle release RT – IMA scenario. Box plots (left). Comparisons between medium and other urgency levels with red boxes indicating significant differences (right).

6.2.2.2 Brake Press

When considering the brake press response for the IMA scenario, duty cycle provided significant reults. Fundamental frequency and tempo had large effects that did not reach significance. For fundamental frequency, there was no statistical difference between levels. Figure 25 illustrates the largest effect between the high-high urgency level compared to the medium urgency level. For duty cycle, the low-low and medium-Low urgency levels produced longer reaction times compared to the medium urgency level (Figure 26). For tempo, although not statistically significant, the low-low urgency level produced longer reaction times compared to the medium urgency level of almost a second (Figure 27).

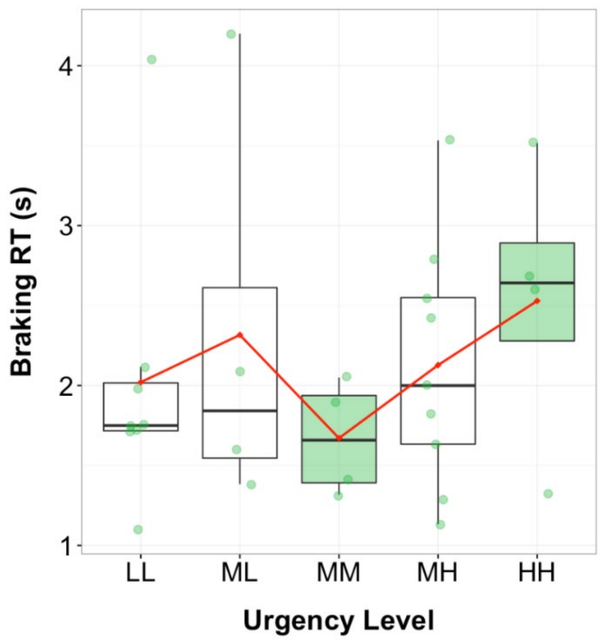

Figure 25 Fundamental frequency brake press RT – IMA scenario box plots

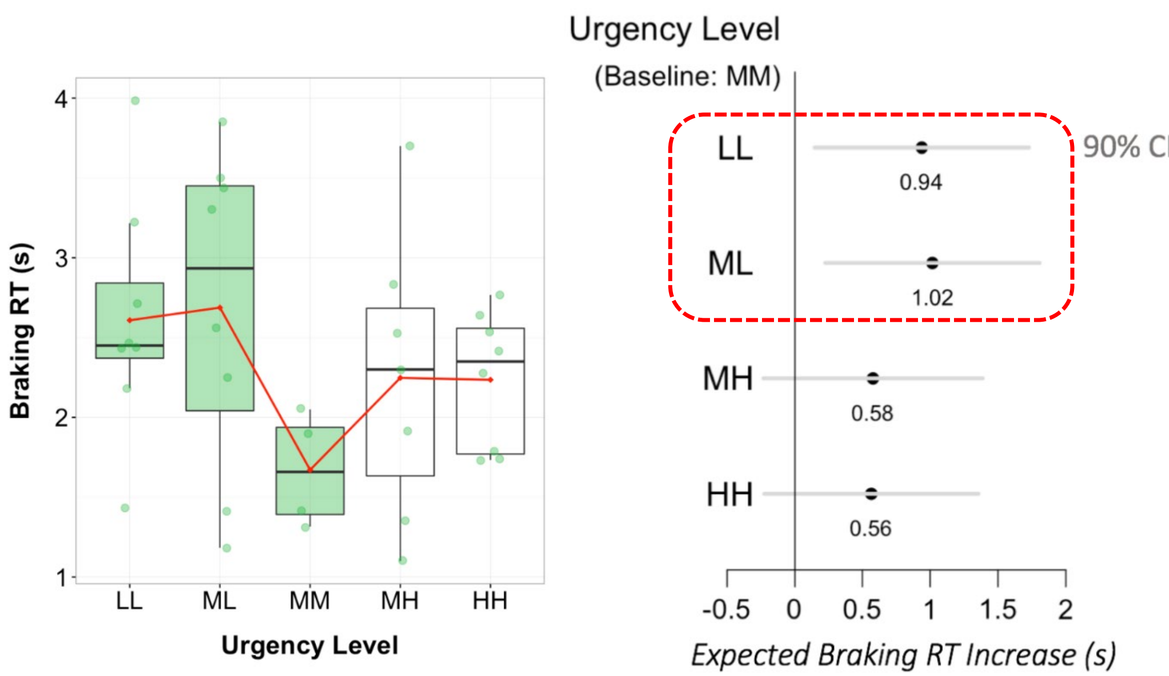

Figure 26 Duty cycle brake press RT – IMA scenario. Box plots (left). Comparisons between medium and other urgency levels with a red box indicating significant differences (right).

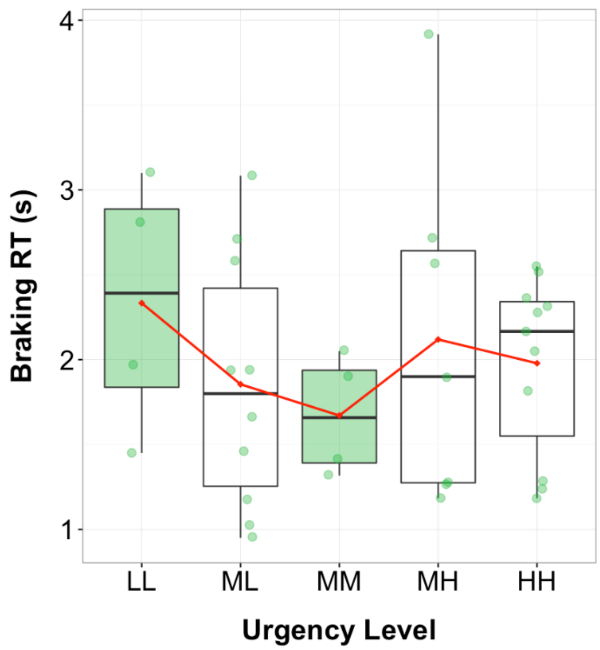

Figure 27 Tempo brake press RT – IMA scenario. Box plot.

6.2.2.3 Max Deceleration

When considering maximum deceleration for the IMA scenario, tempo provided significant difference among urgency levels. For tempo, the high-high urgency levels produced lower levels of maximum deceleration compared to the medium urgency level as can be seen in Figure 28. No effects were observed for fundamental frequency or duty cycle.

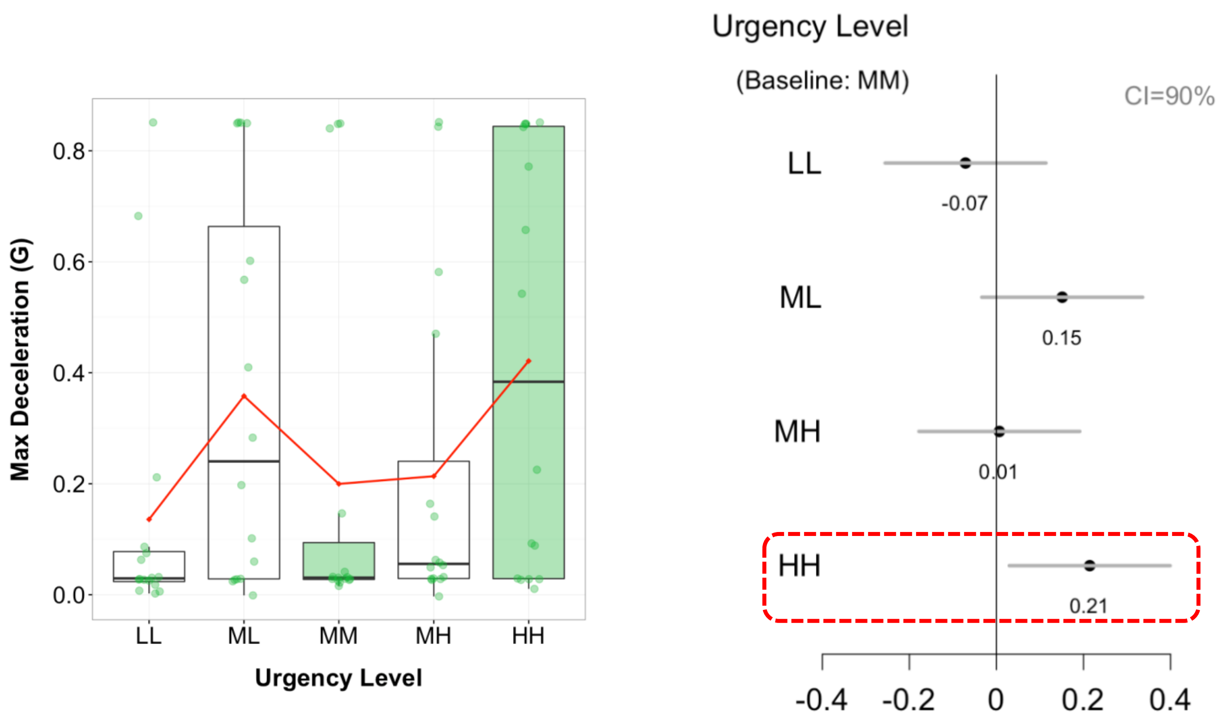

Figure 28 Tempo max deceleration – IMA scenario. Box plots (left). Comparisons between medium and other urgency levels with a red box indicating significant differences (right).

6.2.3 Subjective Data

This section summarizes the results of the subjective evaluation of the auditory alerts for IMA systems. These analyses considered the effects of changes in fundamental frequency, duty cycle, and tempo on the subjective assessment of the alerts. Figure 29 to Figure 31 focus on the noticeability of alert. As can be seen in the figures, the low-low urgency level for duty cycle produced lower levels of perceived intensity. Figure 32 and Figure 33 focus on the effectiveness of the alert. As can be seen in the figures, the medium-high urgency level for tempo produced lower levels of perceived helpfulness. Figure 34 and Figure 35 focus on the understandability of the alert. As can be seen in the figures, the high-high urgency level for tempo produced higher levels of perceived understandability.

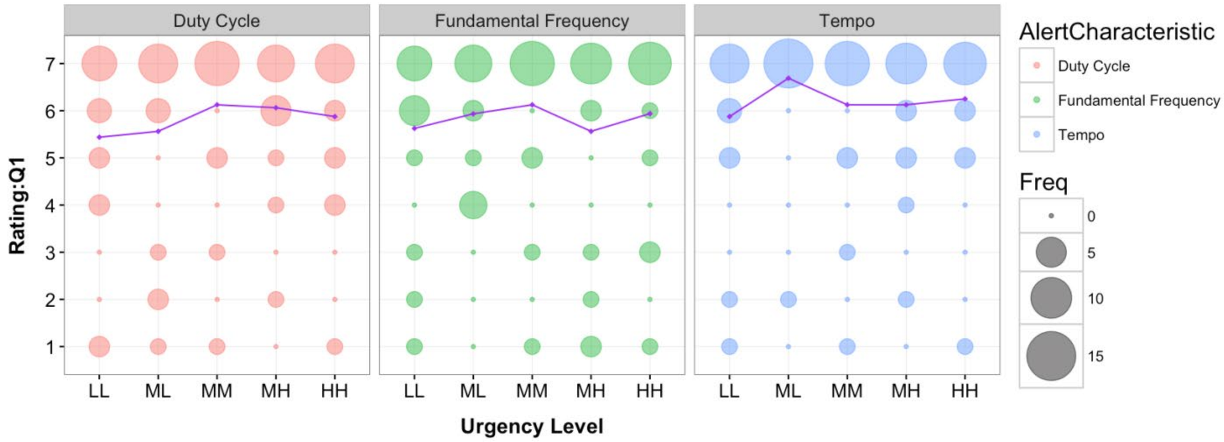

Figure 29 IMA noticeability - The alert: Did not catch my attention(1)…Caught my attention(7)

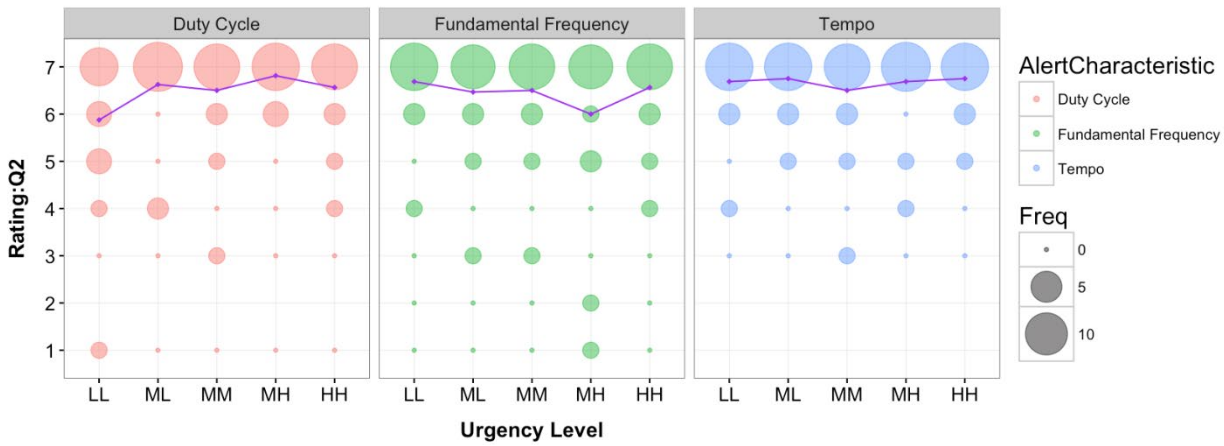

Figure 30 IMA noticeability - The intensity of the alert was: Very difficult(1)…Very easy(7)

Figure 31 IMA noticeability – The intensity of the alert was: Too weak(1)… Too strong(7)

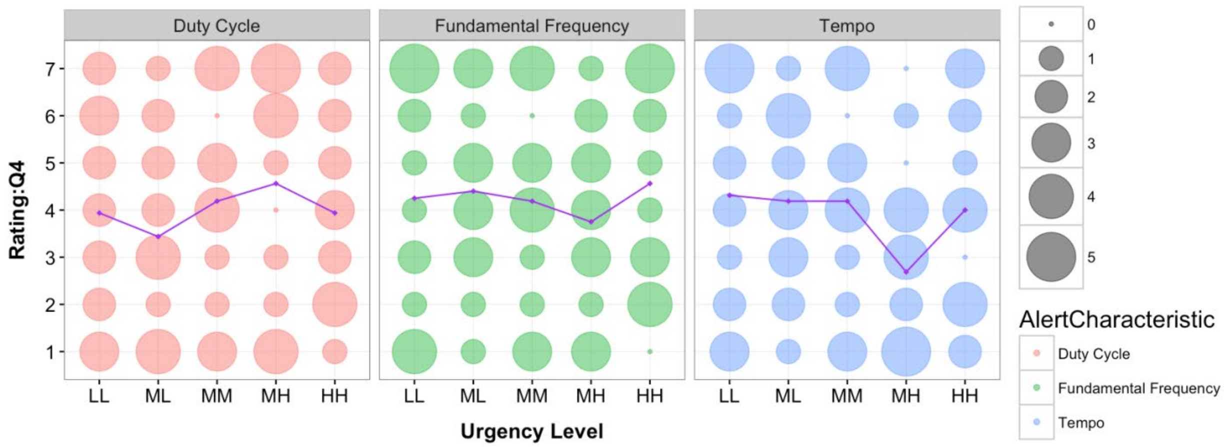

Figure 32 IMA effectiveness – Rate how helpful the collision warning was in identifying vehicles in front of you: Not helpful(1)…Very helpful(7)

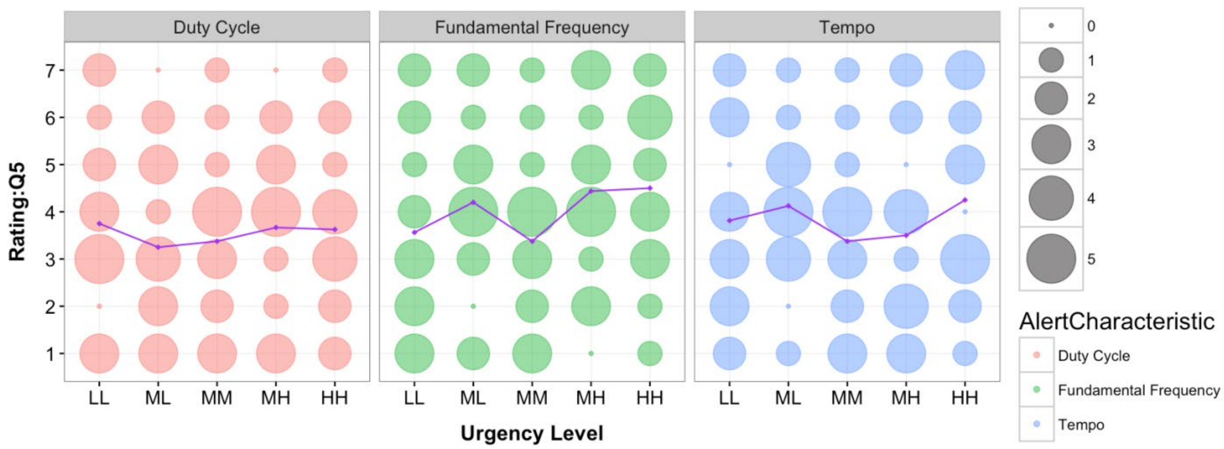

Figure 33 IMA effectiveness – The collision warning affected my driving: Negatively(1)… Positively(7)

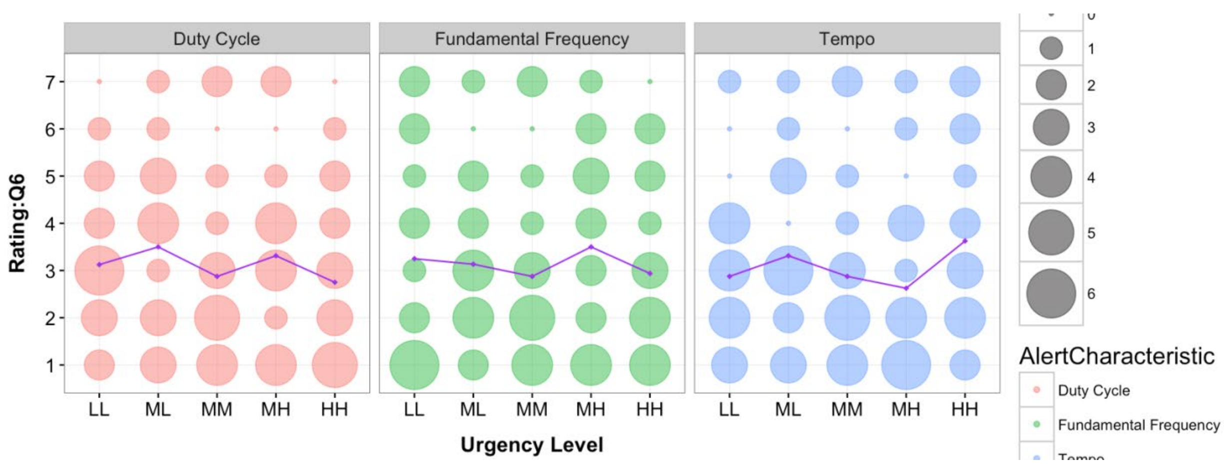

Figure 34 IMA understandability – My ability to interpret the information presented by the alert was: Very difficult(1)…Very easy(7)

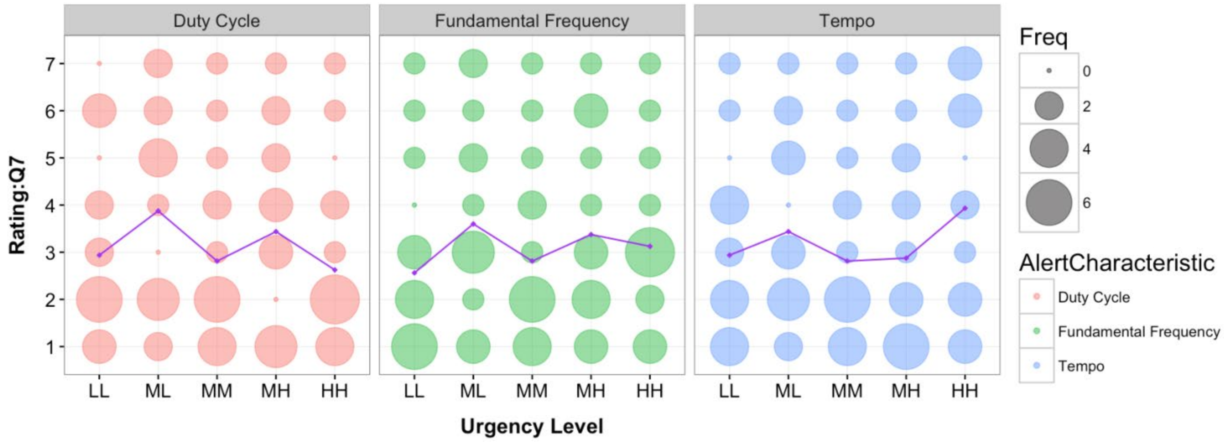

Figure 35 IMA understandability – My ability to understand why the alert was presented was: Very difficult(1)…Very easy(7)

6.2.4 Differences among Sites

The data was collected at four sites: College Station, Iowa City, Seattle, and Washington, District of Columbia. Similarly to the FCW testing there may have been some variation in geographical regions and testing at these four sites provides accountability for any differences.

6.2.4.1 Outcome of Crash Event

The crash frequency and crash rate varied by data collection sites for the IMA scenario (see Table 10). However, the differences among sites were not statistically significant. Compared to the other sites, Iowa City (NADS) had the highest number of crashes and highest crash rate.

Table 10 Crash Frequency and Rate among Data Collection Sites - IMA Scenario

	Data Collection Site			
	College Station (TTI)	Iowa City (NADS)	Seattle (UW)	Washington (Leidos)
Crash Frequency & Crash Rate	46 (90.2%)	49 (96.1%)	46 (88.5%)	45 (88.2%)

6.2.4.2 Driver Performance

There were significant differences among data collection sites for brake reaction time for the IMA scenario (Figure 36). Participants from Iowa City (NADS) braked more slowly than participants in the other three sites. Brake press reaction times for participants from Iowa City (NADS) were 0.3-0.4 seconds ($p<0.1$) slower on average.

There were no significant differences among data collection sites in terms of throttle release reaction time and maximum deceleration.

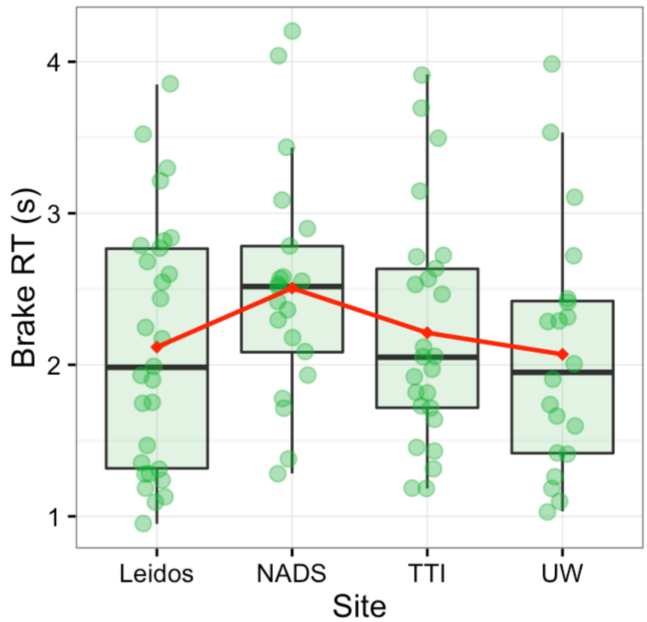

Figure 36 Brake press RT among data collection sites – IMA scenario

7 LEFT-TURN-ACROSS-PATH STUDY

7.1 Specific Method

7.1.1 Driving Scenario

As in the junction-crossing scenario, a researcher instructed participants to follow the directional signs to Shelby. Once comfortably seated in the simulator their drive began. The drive began with the participant's vehicle parked on the side of the road and the participant was instructed to begin driving. Once on the roadway, the simulator instructed the participant to steer left and right in their lane to become familiar with steering in the simulator. The posted speed limit was 45 mph. The participant encountered intersections at regular intervals preceded by directional signs to Shelby indicating whether participants should turn left, right, or continue straight. A subset of the intersections contained traffic signals. All traffic signals were green for the participant throughout the drive. Approximately ten minutes into the drive, the participant passed a directional sign indicating Shelby was to the left and approached a signalized intersection with a red light. A heavy truck was in the oncoming left-turn lane blocking the driver's line of sight. The participant moved into the left-turn lane and came to a stop. The left-turn arrow on the signal turned green and the participant began to move through the intersection. When the participant began to move, the simulator created the incursion vehicle as oncoming traffic. As the participant proceeded through the intersection, the connected vehicle LTAP alert was triggered before the incursion vehicle was visible to the driver. Figure 37 provides a summary of the LTAP event. Figure 38 provides a visualization of the driving scene at the time of the warning.

Figure 37 Timing of left turn across path with alert event

Figure 38 LTAP scenario at point alert is issued

As with the junction-crossing scenario, the distraction task was not necessary as the IMA warning was representative of a V2V system capable of alerting drivers to the presence of a threat before it is visible. The incursion vehicle became visible to the driver after the alert.

7.1.2 Participants

Table 11 provides the distribution of gender and age for this study. For the three varying alert characteristics (fundamental frequency, duty cycle, tempo), the characteristic being tested is the only condition to be tested. All other characteristics were held at the "medium" level. This design resulted in a total of 16 unique participants per cell in the scenario. There were a total of 416 participants from four sites for the left turn. Table 12 provides the distribution of participants per experimental condition.

Table 11 Participant Age and Gender at each Data Collection Site for the Junction Crossing with IMA and LTAP Scenarios

Age group	Male	Female	Total
25-40	N=13	N=13	26
41-55	N=13	N=13	26
Total	26	26	52

Table 12 Participants per Experimental Condition for the Rear-End with LTAP Scenario

	Low-Low (LL)	Medium-Low (ML)	Medium (MM)	Medium-High (MH)	High-High (HH)
Fundamental Frequency	16 total 4 per site	16 total 4 per site	16 total 4 per site	16 total 4 per site	16 total 4 per site
Duty Cycle (% time present)	16 total 4 per site	16 total 4 per site		16 total 4 per site	16 total 4 per site
Tempo (pulses/second)	16 total 4 per site	16 total 4 per site		16 total 4 per site	16 total 4 per site
	208 Total participants across four sites 52 participants per site				

7.2 Results

7.2.1 Outcome

When considering the outcome of the LTAP scenario, the rate of crashes varied by experimental condition (Table 13). For fundamental frequency, the medium-Low level produced the fewest crashes. For duty cycle, the high-high level produced the fewest crashes. For tempo, the medium-high levels produced the fewest crashes.

Table 13 LTAP Crash Frequency

Condition	**Urgency Level**				
	Low-Low (LL)	Medium-Low (ML)	Medium (MM)	Medium-High (MH)	High-High (HH)
Fundamental Frequency	4 27%	1 6%	3 19%	3 19%	2 15%
Duty Cycle	6 43%	1 8%		1 7%	0 0%
Tempo	3 20%	2 13%		1 7%	2 13%

7.2.2 Driver Performance

Driver response in terms of throttle release time and brake reaction time characterizes driver response to the alerts associated with FCW scenarios. Additionally, maximum deceleration provides a measure of driver response.

7.2.2.1 Throttle Release

When considering the throttle release response for the LTAP scenario, duty cycle, for young drivers, produced significant results. For duty cycle, the low-low urgency level produced longer release times compared to the medium urgency level when young drivers were considered (Figure 39). Fundamental frequency and tempo produced no significant effects.

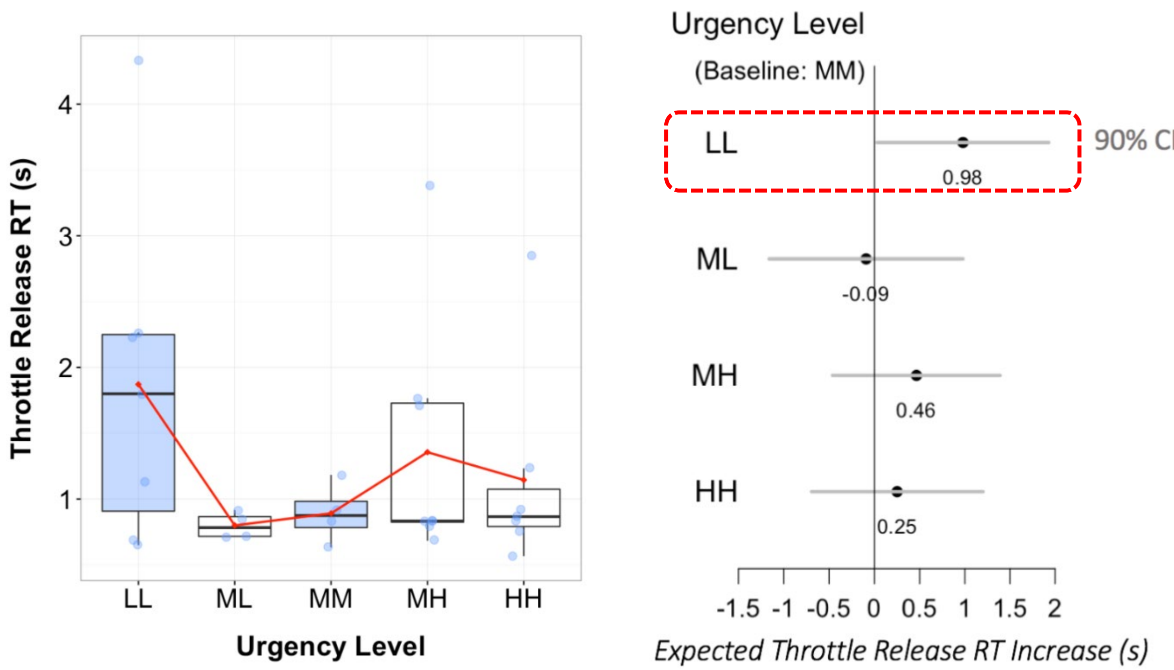

Figure 39 Duty cycle throttle release RT – LTAP scenario for young drivers. Box plots (left). Comparisons between medium and other urgency levels with a red box indicating significant differences (right).

7.2.2.2 Brake Press

When considering the brake press response for the LTAP scenario, there were no significant effects.

7.2.2.3 Max Deceleration

When considering maximum deceleration for the LTAP scenario, there were no significant effects.

7.2.3 Subjective Data

This section summarizes the results of the subjective evaluation of the auditory alerts for LTAP systems. These analyses considered the effects of changes in fundamental frequency, duty cycle, and tempo on the subjective assessment of the alerts. Figure 40 to Figure 42 focus on the noticeability of alert. As can be seen in the figures, perceived noticeability generally increased with duty cycle in the range tested with the exception of catching the driver's attention for the high-high urgency level. For fundamental frequency, the low-low urgency level produced the least noticeability. As can be seen in the figures, the low-low urgency level produced the lowest ratings of helpfulness for duty cycle, fundamental frequency, and tempo. For duty cycle, the positive effect of the alert increased as a function of urgency level. For tempo, medium-high and high-high levels of urgency produced more positive perceptions of effect. Figure 43 and Figure 44 focus on the effectiveness of the alert. Figure 45 and Figure 46 focus on the understandability of the alert. As can be seen in the figures, there are not consistent patterns across urgency levels. For duty cycle and tempo, the medium-high urgency levels produced the greatest understandability. For fundamental frequency, the high-high urgency level produced the greatest understandability.

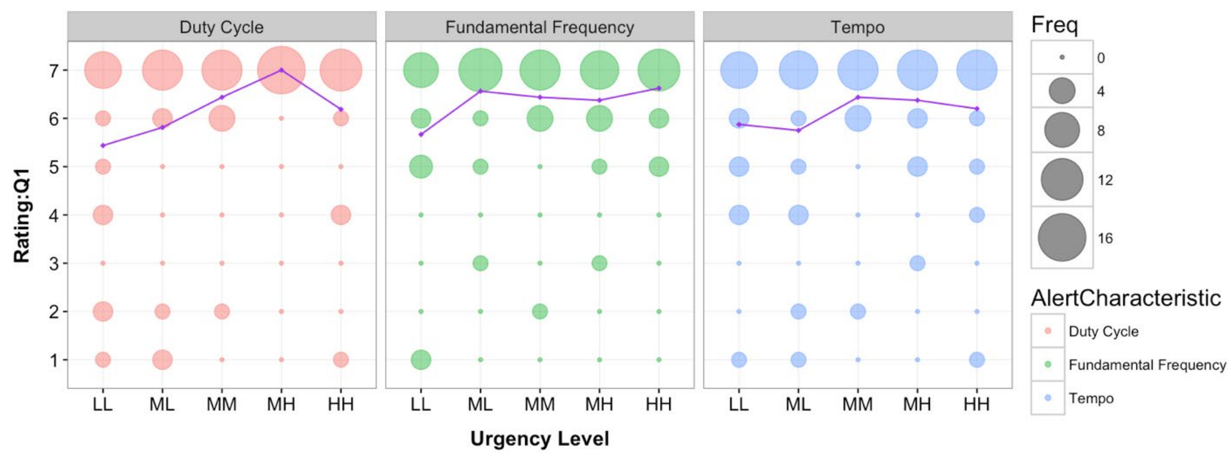

Figure 40 LTAP noticeability - The alert: Did not catch my attention(1)… Caught my attention(7)

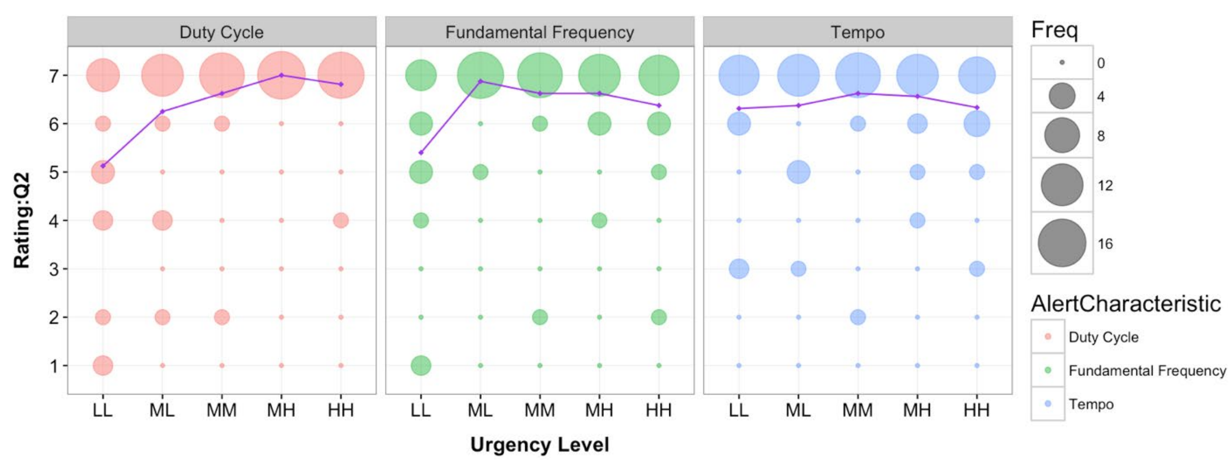

Figure 41 LTAP noticeability - The intensity of the alert was: Very difficult(1)…Very easy(7)

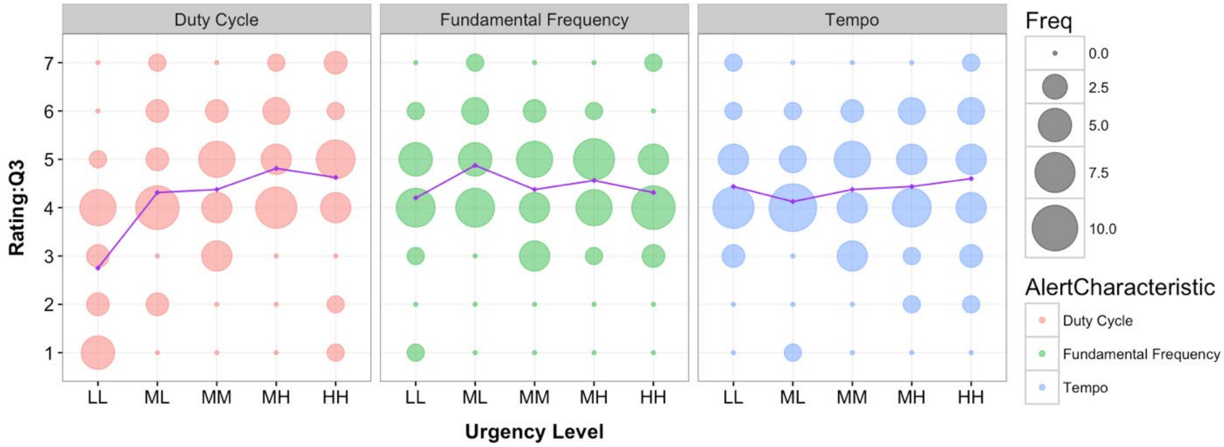

Figure 42 LTAP noticeability – The intensity of the alert was: Too weak(1)… Too strong(7)

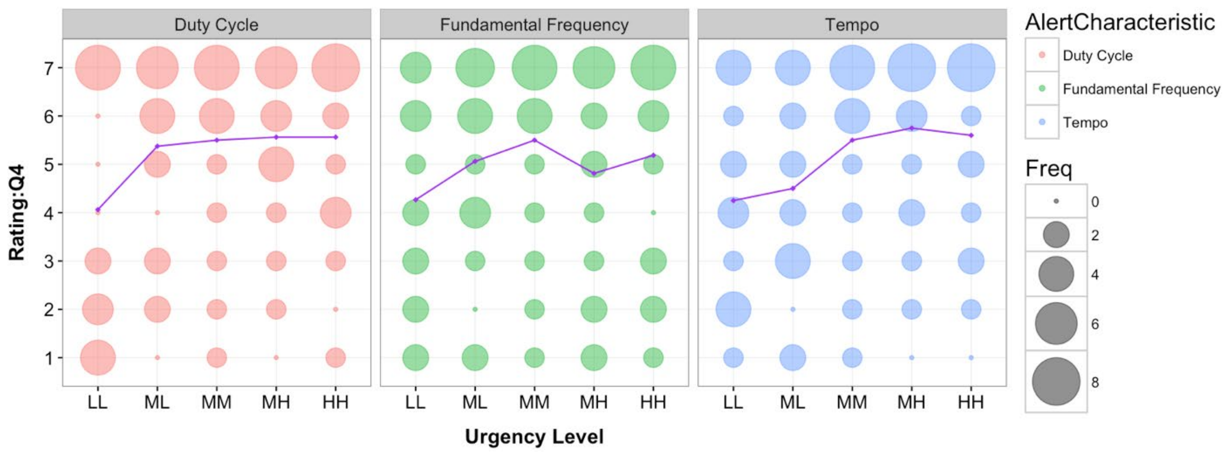

Figure 43 LTAP effectiveness – Rate how helpful the collision warning was in identifying vehicles in front of you: Not helpful(1)…Very helpful(7)

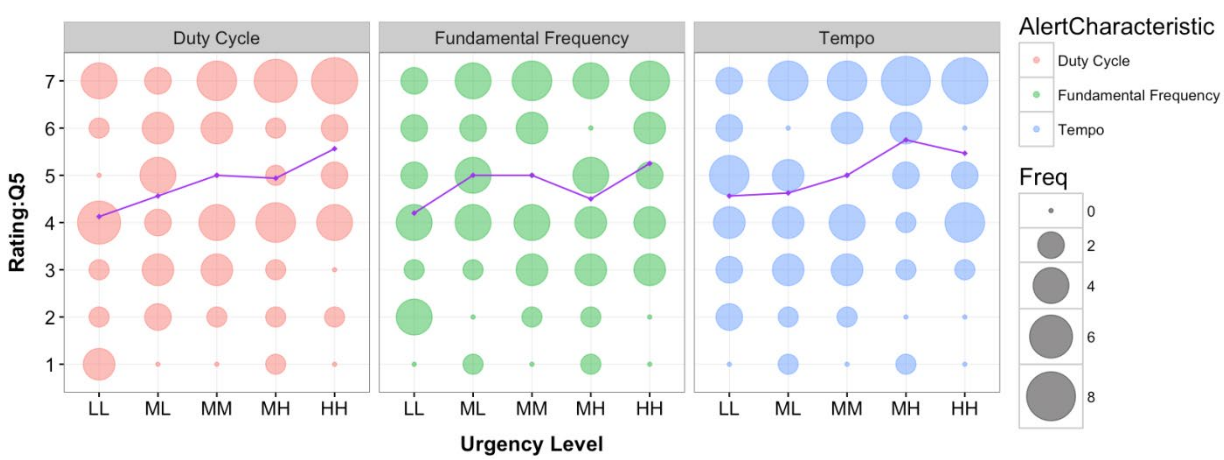

Figure 44 LTAP effectiveness – The collision warning affected my driving: Negatively(1)… Positively(7)

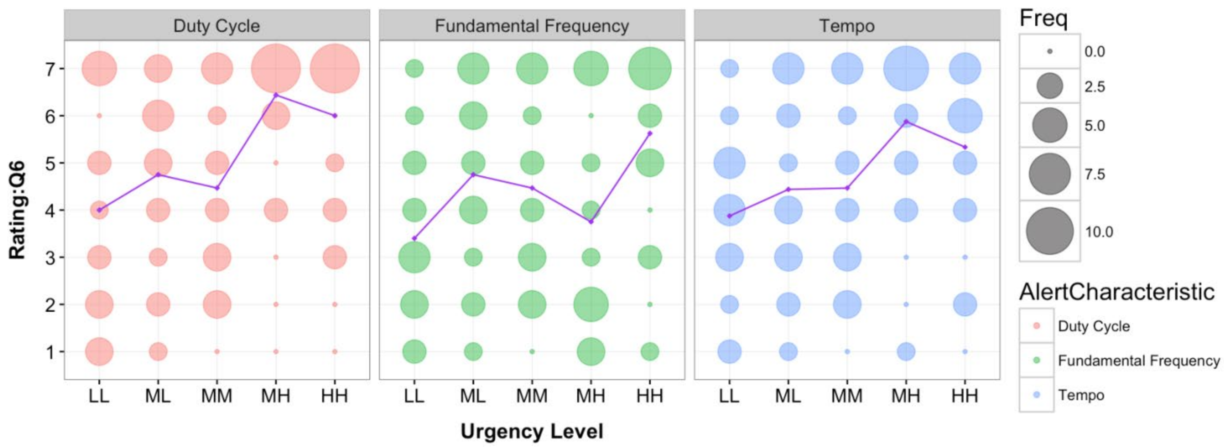

Figure 45 LTAP understandability – My ability to interpret the information presented by the alert was: Very difficult(1)…Very easy(7)

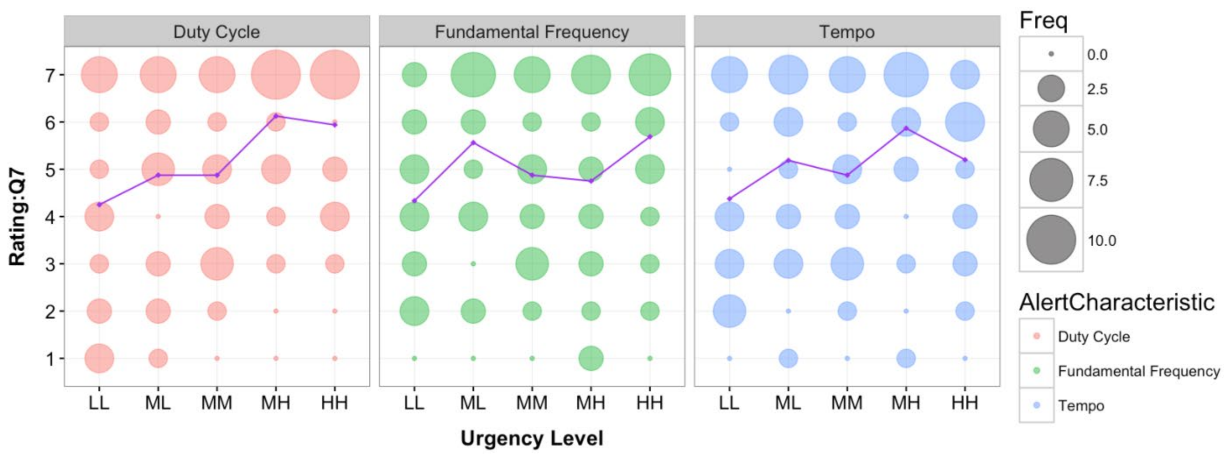

Figure 46 LTAP understandability – My ability to understand why the alert was presented was: Very difficult(1)…Very easy(7)

8 SUMMARY

This research focused on how characteristics of auditory alerts affect driver response in forward-crash and intersection-crash situations in which connected vehicle applications may have a safety benefit. The results indicate that despite the same alert characteristics, reaction time varies by crash event. Additionally, changes in alert characteristics do not necessarily lead to similar changes in effect across crash events. Similarly, subjective data was largely consistent with changes in the response data and varied across event. The results also indicate that whether the driver crashes is determined by not only how quickly the driver responds but also the nature of the response. The results show how characteristics of auditory alerts affect driver response under specific experimental conditions.

Researchers designed the FCW, IMA, and LTAP events in this study to be severe collision events. The driver would crash if they did not respond in a timely and appropriate manner to the warning. Additionally, we employed levels of alert characteristics designed to include ineffective levels due to the exploratory nature of this study. The reported results reflect the severity of the crash situations and the effectiveness of the auditory alert characteristics and are not an indication of the efficacy of the warning systems.

Reaction Time Varies by Crash Event

The first consideration was the extent to which an alert configuration would produce similar responses in different types of event. Ideally, an auditory crash alert should draw the driver's attention to the threat and cause the driver to make a response to avoid the crash situation. This is complicated with connected vehicle alerts that may be alerting the driver to a threat that is not yet visible. Results indicate that when an actual threat is visible, such as the FCW event, or a potential threat can be surmised, such as the LTAP event, drivers respond with similar haste. However, the absence of an obvious threat, such as the IMA event, does not lead to an immediate avoidance response to the alert.

Alert Effectiveness Varies across Events

Moving to the primary focus of this research, studying the how alert effectiveness varies based on the characteristics of the alert, we were hoping that the changes in alert characteristics would provide consistent changes in performance across the three types of crash events. Unfortunately, the results showed that changes in fundamental frequency, duty cycle, and tempo did not produce consistent variations in performance. Table 14 through Table 16 show that although there is some consistency, it is not uniform.

The effects related to duty cycle show the most consistency across the warning types with low-low (0.05) producing slower throttle release and brake press reaction times for the FCW and IMA events. However, fundamental frequency produces less consistent results with high-high (963 Hz) performing worse for the IMA event and inconsistent results for FCW between throttle release and brake press; neither of which match with the IMA results.

Table 14 Differences in Response for Fundamental Frequency Relative to MM

Throttle Release RT	FCW	ML -0.03	MM 0	MH 0.05	MH 0.07	LL 0.11*
	IMA	LL 0.08	MH 0.13	MM 0	ML 0.18	HH 0.37*
	LTAP	No significant differences				
Brake Press RT	FCW	ML -0.03	MM 0	HH 0.06	LL 0.07	MH 0.09*
	IMA	No significant differences				
	LTAP	No significant differences				
*indicates significant difference from MM						

Table 15 Differences in Response for Duty Cycle Relative to MM

		LL	ML	MM	MH	HH
Throttle Release RT	FCW	ML -0.07	HH -0.01	MM 0	MH 0.02	LL 0.19*
	IMA	MM 0	HH 0.07	ML 0.48	LL 0.72*	MH 0.78*
	LTAP	ML -0.09	MM 0	HH 0.25	MH 0.46	LL 0.98*
Brake Press RT	FCW	MM 0	MH 0.01	HH 0.04	ML 0.05	LL 0.15*
	IMA	MM 0	HH 0.56	MH 0.58	LL 0.94*	ML 1.02*
	LTAP	No significant differences				
*indicates significant difference from MM						

Table 16 Differences in Response for Tempo Relative to MM

		LL	ML	MM	MH	HH
Throttle Release RT	FCW	No significant differences				
	IMA					
	LTAP					
Brake Press RT	FCW	No significant differences				
	IMA					
	LTAP					

Subjective Data Similar to Performance Data

Although subject assessment of the alert characteristics was not the primary focus of this research, it is important to consider the extent to which the driver perceptions of system effectiveness align with the effects on reaction time. As was described in the in the results section for each of the alert characteristics, there was a general agreement between the reaction times and the trends in the subjective responses. Although not critical for drivers to perceive alerts as effective, agreement does help to reinforce the driver reaction time data.

Crash Rate Inconsistent across Events

After considering driver initial response, the next consideration becomes the extent to which the variation in alert characteristic affected the outcome of the event. Overall, there was not a consistent crash rate across the three types of events due to differences in the kinematics of the driving situations. In general, the LTAP event had the fewest crashes, followed by the FCW event. For the IMA event, most all participants crashed. The other complexity of crash outcome is the choice of response: despite each driver being exposed to the same situation, variations in choice of initial and overall response were observed with combinations of throttle release, brake press, throttle press, and steering. Additionally, in events with the same types of response, the choice of response intensity also varied. When considering how the changes in characteristics affected performance across events in our study, a medium-Low fundamental frequency (234 Hz) resulted in fewer crashes and medium-Low and medium-high duty cycles (0.25 and 0.75, respectively) resulted in fewrer crashes. Changes in tempo had little effect on crash rate. It is also important to consider that this research did not consider all combinations of variations in characteristics. If these results were to be generalized, we would expect similar trends in outcome.

Considering Driver Performance and Crash Rate

When considering the overall impact, performance, and crashes for fundamental frequency, duty cycle, and tempo, the picture becomes complex. For fundamental frequency, three of the levels tested showed increases in reaction time and only one level showed and reduction in crash risk. There was no overlap between these levels that would indicate a clear selection. For fundamental frequency around 234 Hz performed well, whereas fundamental frequencies over 319 Hz or near 115 Hz performed poorly. For duty cycle, the choice of cut-offs is less clear. The low-low (0.05%) duty cycle showed an increase in reaction times. Greater distinctions are more complex as the medium-Low and medium-high duty cycles show a reduction in crash rate despite an increase in reaction time for some situations. For tempo, under none of the levels was there a significant change in crash rate. There is, however, some evidence that the lowest level of tempo (1 pulse per second) can slow reaction time.

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10 APPENDICES

10.1 Appendix A - Phone Screening

V2V Safety Applications

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 1 study visit that will last approximately 1 hour. You will be required to come to University Research Park (formerly the Oakdale Campus) to participate.

Participation involves signing a consent form, driving a simulator and completing some surveys. You will receive instructions regarding driving the simulator cab and the study drive 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

1

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 3,500 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)

10) **Do you ever engage in behavior that may be distracting while driving such as: talking on your cell phone, sending or receiving text messages, eating, sending or receiving emails, or reading?**
    (must answer yes)

11) **Are you a native English speaker?**
    (must answer yes)

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 and only a record of your motion sickness susceptibility will be kept as part of this study.**
- **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 aides - 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
Proceed to Closing

6

Closing

MEETS ALL CRITERIA

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 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.
- Request the following of all participants:
  - Wear flat shoes to drive in
  - No hats worn or gum chewing allowed while driving
  - Refrain from wearing artificial scents (perfume or cologne) as some staff allergic to scents
- If your appointment is before 8am or after 5pm, the front door will be locked, so 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, please use the After Hours Call Box located at the right side on the front door. Press the call button and someone will let you in.
- Provide directions, explain where to park.
- Inform participants to call **(319) 335-4719** if they are unable to make this appointment and need to reschedule as soon as possible (prefer 24 hour notice). Please leave a message if they receive voicemail and a staff member will return their call.

DOES NOT MEET CRITERIA:

- 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.
- If participant is not in our database, ask if they would like to be considered for future driving research studies, if yes, fill out NADS database form.

10.2 Appendix B – FCW Informed Consent

FOR IRB USE ONLY
APPROVED BY: IRB-02
IRB ID #: 201310738
APPROVAL DATE: 07/15/14
EXPIRATION DATE: 10/12/14

INFORMED CONSENT DOCUMENT

Project Title: NHTSA V2V Safety Applications Study

Principal Investigator: Dawn Marshall

Research Team Contact: Dawn Marshall, 319-335-4774

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 cross the US.

HOW MANY PEOPLE WILL PARTICIPATE?

Approximately 250 people will take part in this study at the University of Iowa. Up to 500 people will also take part at other locations across the US.

HOW LONG WILL I BE IN THIS STUDY?

If you agree to take part in this study, your involvement will last for 1 to 1 1/2 hours.

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 complete a questionnaire that covers some general questions about your demographics (date of birth, gender, marital status, income, occupation ethnicity and education level), driving experience, vision, the vehicle you drive, hearing, and motion sickness. You will then watch a presentation that describes the driving simulator and the task you will do while driving.

Then you will complete the first study drive, which will last approximately 7-10 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 and a questionnaire about your perceptions of the drive. Then you will complete another similar drive.

Following the simulator drives, you will be asked to fill out 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.

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 involving 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 if and 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're not feeling ill effects.

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 $50. 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 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,
- 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 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

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 won't 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.

FOR IRB USE ONLY
APPROVED BY: IRB-02
IRB ID #: 201310738
APPROVAL DATE: 07/15/14
EXPIRATION DATE: 10/12/14

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: 10/12/14 .

____ ______________________________

(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)

10.3 Appendix C – ICW Informed Consent

FOR IRB USE ONLY
APPROVED BY: IRB-02
IRB ID #: 201310738
APPROVAL DATE: 08/04/15
EXPIRATION DATE: 08/03/16

INFORMED CONSENT DOCUMENT

Project Title: NHTSA V2V Safety Applications Study

Principal Investigator: Dawn Marshall

Research Team Contact: Dawn Marshall, 319-335-4774

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 cross the US.

HOW MANY PEOPLE WILL PARTICIPATE?

Approximately 400 people will take part in this study at the University of Iowa. Up to 1000 people will also take part at other locations across the US.

HOW LONG WILL I BE IN THIS STUDY?

If you agree to take part in this study, your involvement will last for 1 to 1 1/2 hours.

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 complete a questionnaire that covers some general questions about your demographics (date of birth, gender, marital status, income, occupation ethnicity and education level), driving experience, vision, the vehicle you drive, hearing, and motion sickness. You will then watch a presentation that describes the driving simulator and the task you will do while driving.

Then you will complete the study drive, which will last approximately 7-10 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 and a questionnaire about your perceptions of the drive.

Following the simulator drive, you will be asked to fill out 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.

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 involving 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 if and 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're not feeling ill effects.

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 $50. 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 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,
- 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 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

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 won't 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.

FOR IRB USE ONLY
APPROVED BY: IRB-02
IRB ID #: 201310738
APPROVAL DATE: 08/04/15
EXPIRATION DATE: 08/03/16

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: 08/03/16 .

_________________________________ _______________________
(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)

10.4 Appendix D – Driving Questionnaire

Participant number: Date: Site:

DRIVING QUESTIONNAIRE

As part of this study, it is useful to collect information describing each participant. The following questions ask about your basic demographic information, health, driving frequency and patterns. Please read each question carefully. If something is unclear, ask the research assistant for help. Your participation is voluntary and you may skip any questions that you do not want to answer.

Background Information

1) What is your birth date? ____ / ____ / ____
Month Day Year

2) What is your gender?

❒Male
❒Female

3) What is your marital status? (Check only one)

❒Single
❒Married
❒Domestic Partnership
❒Separated or Divorced
❒Widowed

4) What was your total household income last year? (Check only one)

❒0 - $20,000
❒$20,000 - $29,999
❒$30,000 - $39,999
❒$40,000 - $49,999
❒$50,000 - $59,999
❒$60,000 - $69,999
❒$70,000 - $79,999
❒$80,000 or more

5) What is your present employment status? (Check only one)

❒Unemployed
❒Retired
❒Work part-time
❒Work full-time
❒None of the above

6) What type of work do you do (e.g., teacher, law enforcement official, homemaker)?

____

7) 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

8) What is the highest level of education that you have completed? (Check only one)

❒Primary School
❒High School Diploma or equivalent
❒Technical School or equivalent
❒Some College or University
❒Associate's Degree
❒Bachelor's Degree
❒Some Graduate or Professional School
❒Graduate or Professional Degree

1

Driving Experience

9) How old were you when you started to drive? ____ years of age

10) On average, how many days in a week (out of 7 days) do you drive?
❑0 ❑1 ❑2 ❑3 ❑4 ❑5 ❑6 ❑7

11) How many work-related miles do you drive in last year? (Check only one)
❑Under 2,000
❑2,000 - 7,999
❑8,000 - 12,999
❑13,000 - 19,999
❑20,000 or more

12) What speed do you typically drive on the highway when the speed limit is 55 miles per hour?
❑Below 45
❑45 - 49
❑50 - 54
❑55
❑56 - 60
❑61 - 64
❑65 - 69
❑70 - 74
❑Above 74

13) What speed do you typically drive on the highway when the speed limit is 65 miles per hour?
❑Below 55
❑55 - 59
❑60 - 64
❑65
❑66 - 70
❑71 - 74
❑75 - 79
❑80 - 84
❑Above 84

14) What speed do you typically drive on the highway when the speed limit is 70 miles per hour?
❑Below 60
❑60 – 64
❑65 - 69
❑70
❑71 – 74
❑75 - 79
❑80 - 84
❑Above 84

15) Have you ever participated in any driving training program (e.g., Graduated Driver Licensing program, CDL Truck Training Schools)?
❑No
❑Yes (Please describe) ____

____

Personal Vehicle

16) What type of automobile do you drive most often?

Year	Make (e.g., Ford, Toyota)	Model (e.g., Escort, Celica)
__ __ __ __	____________________	____________________

17) Which of the following features does your automobile have? (Check all that apply)

- ❐ None of these
- ❐ Adaptive Cruise Control (ACC)
- ❐ Lane Departure Warning (LDW)
- ❐ Lane Change Assistance
- ❐ Forward Collision Avoidance System
- ❐ Intelligent Speed Adaptation or Intelligent Speed Advice (ISA)
- ❐ Automotive Night Vision
- ❐ Adaptive Light Control
- ❐ Automatic Parking
- ❐ Blind Spot Detection (BSD)
- ❐ Driver Drowsiness Detection
- ❐ Hill Descent Control (HDC)
- ❐ Others

Please list: ____

And how oftenyou use the ADAS when you are driving?
❐ Never ❐ Rarely ❐ Sometimes ❐ Often ❐ Always

18) How many vehicles are in your household? ______________________

Violations and Accidents

19) Within the past five years, how many moving violations have you received? _________

20) Within the past five years, have you received a ticket for any of the following? (Please check No or Yes for each)

	No	Yes
Speeding	❐	❐
Going too slowly	❐	❐
Failure to yield right of way	❐	❐
Disobeying traffic lights	❐	❐
Disobeying traffic signs	❐	❐
Using cellphone while driving	❐	❐
Driving without using the seatbelt	❐	❐
Following another car too closely	❐	❐
Driving while intoxicated	❐	❐
Other (please specify) ________________________________		

21) In the past five years, how many times have you been the driver of a car involved in a crash?

❒0 (Go to question 23)
❒1
❒2
❒3
❒4 or more

Please provide the following information about the last crash.

	No	Yes
Was another vehicle involved?	❒	❒
Was a pedestrian involved?	❒	❒
Were you largely responsible for this accident?	❒	❒
Did you go to driver's rehabilitation?	❒	❒

Weather Condition: ____________________
Month/Year: ____________________
Brief Description: ____________________
____

22) In the past five years, how many times have you been the driver of a car involved in a rear-end crash?

❒0 (Go to question 23)
❒1
❒2
❒3
❒4 or more

Please provide the following information about the last rear-end crash.

	No	Yes
Was another vehicle involved?	❒	❒
Was a pedestrian involved?	❒	❒
Were you largely responsible for this accident?	❒	❒
Did you go to driver's rehabilitation?	❒	❒

Weather Condition: ____________________
Month/Year: ____________________
Brief Description: ____________________
____

Vision and Hearing

23) What type of prescription glasses or contact lenses will you be wearing for today's study? (Check only one)

❒ None (Go to question 25)
❒ Single Lens Glasses
❒ Bifocals
❒ Trifocals
❒ Contact Lenses

24) What type of vision problem do you have? (Check only one)

❒ Near-sighted - can only see items that are near without glasses
❒ Far-sighted - can only see items that are far away without glasses
❒ Near and Far sighted - cannot see items that are near or far without glasses
❒ Other, explain ____________________

25) Do you have any known hearing problems?
❒ No ❒ Yes

26) Do you currently use a hearing aid?
❒ No ❒ Yes

27) Please check the boxes for the situations that apply to you.

❒ I sometimes feel that people are not speaking clearly (mumbling).

❒ When people address me from behind or from a few feet away, I have difficulty understanding them.

❒ I have difficulty understanding people in meetings or group discussions.

❒ In situations with a high noise level (e.g., in restaurants, at parties or at the airport), I have difficulty understanding other people.

❒ I find it hard to hear birds singing, footsteps, running water, and other soft everyday sounds.

❒ I sometimes fail to hear the doorbell or telephone.

❒ I turn the television or radio up louder than other people. When someone else controls the volume, I have problems understanding.

❒ Other people have told me that I don't hear well.

Motion sickness

28) How often do you experience motion sickness? (Circle only one)
0 1 2 3 4 5 6 7 8 9 10
Never Always

29) How severe are your symptoms when you experience motion sickness (Circle only one)
0 1 2 3 4 5 6 7 8 9 10
None Severe

30) Have you taken any medication in the past 48 hours?
❒ No
❒ Yes (Please list all) ____

31) Have you consumed any alcohol or other drugs in the past 24 hours?
32) ❒ No
❒ Yes (Please list all)) ____

Other Studies

33) Have you participated in other driving studies?

❒No (End of questionnaire)
❒Yes (please provide details for each study you have participate in below)

Study 1
What vehicle was used for this study? (Check only one)

❒Actual car - only
❒Simulator - only
❒Both - actual car and simulator

Brief Description: ______________________________

____

____

Study 2
What vehicle was used for this study? (Check only one)

❒Actual car - only
❒Simulator - only
❒Both - actual car and simulator

Brief Description: ______________________________

____

____

10.5 Appendix E – FCW Acceptance Questionnaire (With Warning)

Forward Collision Warning Post Drive Acceptance Questionnaire

A alert from a **Forward Collision Warning System** activated when there was a potential collision with a vehicle in front of you. Please read each question carefully and circle 1 - 7 for each question. If something is unclear ask the research assistant for help. Your participation is voluntary, and you have the right to omit questions you choose not to answer.

1	The alert...	Did not catch my attention 1	2	3	4	5	6	Caught my attention 7
2	The alert was...	Very Distracting 1	2	3	4	5	6	Not Distracting 7
3	My ability to hear the alert was ...	Very Difficult 1	2	3	4	5	6	Very Easy 7
4	The intensity of the alert was...	Too Weak 1	2	3	4	5	6	Too Strong 7
5	The timing of the alert was...	Too Early 1	2	3	4	5	6	Too Late 7
6	Rate how helpful the forward collision warning was in identifying vehicles in front of you.	Not Helpful 1	2	3	4	5	6	Very Helpful 7
7	The forward collision warning affected my driving...	Negatively 1	2	3	4	5	6	Positively 7
8	My ability to interpret the information presented by the alert was...	Very Difficult 1	2	3	4	5	6	Very Easy 7
9	My ability to understand why the alert was presented was...	Very Difficult 1	2	3	4	5	6	Very Easy 7
10	My feelings about have a forward collision warning system in my next vehicle	Definitely Would Not 1	2	3	4	5	6	Definitely Would 7

17. What was your degree of ***self confidence*** to handle vehicles slowing in front of you?

- ❒ Not at all confident
- ❒ Slightly confident
- ❒ Moderately confident
- ❒ Very confident
- ❒ Extremely confident

10.6 Appendix F – FCW Acceptance Questionnaire (No Warning)

Study: V2VSA___
Participant: __________
Date: __________

Forward Collision Post Drive Acceptance Questionnaire
(No Warning)

The following question asks about your study drive and about your opinions related to the potential collisions with a vehicle in front of you. Please read each question carefully. If something is unclear ask the research assistant for help. Your participation is voluntary, and you have the right to omit questions you choose not to answer.

1. What was your degree of ***self confidence*** to handle potential collisions with another vehicle in front of you?
   - ❐ Not at all confident
   - ❐ Slightly confident
   - ❐ Moderately confident
   - ❐ Very confident
   - ❐ Extremely confident

10.7 Appendix G – ICW Acceptance Questionnaire (With Warning)

Study: V2VSA- Phase 2
Participant: __________
Date: __________

Intersection Collision Warning Post Drive Acceptance Questionnaire

A alert from an **Intersection Collision Warning System** activated when there was a potential collision with a vehicle crossing your path at an intersection. Please read each question carefully and circle 1 - 7 for each question. If something is unclear ask the research assistant for help. Your participation is voluntary, and you have the right to omit questions you choose not to answer.

1	The alert...	Did not catch my attention 1	2	3	4	5	6	Caught my attention 7
2	The alert was...	Very Distracting 1	2	3	4	5	6	Not Distracting 7
3	My ability to hear the alert was ...	Very Difficult 1	2	3	4	5	6	Very Easy 7
4	The intensity of the alert was...	Too Weak 1	2	3	4	5	6	Too Strong 7
5	The timing of the alert was...	Too Early 1	2	3	4	5	6	Too Late 7
6	Rate how helpful the intersection collision warning was in identifying vehicles crossing your path.	Not Helpful 1	2	3	4	5	6	Very Helpful 7
7	The intersection collision warning affected my driving...	Negatively 1	2	3	4	5	6	Positively 7
8	My ability to interpret the information presented by the alert was...	Very Difficult 1	2	3	4	5	6	Very Easy 7
9	My ability to understand why the alert was presented was...	Very Difficult 1	2	3	4	5	6	Very Easy 7
10	My feelings about having an intersection collision warning system in my next vehicle	Definitely Would Not 1	2	3	4	5	6	Definitely Would 7

17. What was your degree of ***self confidence*** to handle vehicles crossing your path at interesections?

- ❒ Not at all confident
- ❒ Slightly confident
- ❒ Moderately confident
- ❒ Very confident
- ❒ Extremely confident

10.8 Appendix H – ICW Acceptance Questionnaire (No Warning)

Study: V2VSA-Phase 2
Participant: __________
Date: __________

Intersection Collision Post Drive Acceptance Questionnaire
(No Warning)

The following question asks about your study drive and about your opinions related to the potential collisions with a vehicle crossing your path. Please read each question carefully. If something is unclear ask the research assistant for help. Your participation is voluntary, and you have the right to omit questions you choose not to answer.

1. What was your degree of ***self confidence*** to handle potential collisions with another vehicle crossing your path?
   - ❐ Not at all confident
   - ❐ Slightly confident
   - ❐ Moderately confident
   - ❐ Very confident
   - ❐ Extremely confident

10.9 Appendix I – Wellness Survey

Study: V2VSA

Participant: ________

Date:________

WELLNESS QUESTIONIRE

Directions: Circle one option for each symptom to indicate whether that symptom applies to you right now.

1. General Discomfort .... None .... Slight .... Moderate .... Severe
2. Fatigue .... None .... Slight .... Moderate .... Severe
3. Headache .... None .... Slight .... Moderate .... Severe
4. Eye Strain .... None .... Slight .... Moderate .... Severe
5. Difficulty Focusing .... None .... Slight .... Moderate .... Severe
6. Salivation Increased .... None .... Slight .... Moderate .... Severe
7. Sweating .... None .... Slight .... Moderate .... Severe
8. Nausea .... None .... Slight .... Moderate .... Severe
9. Difficulty Concentrating .... None .... Slight .... Moderate .... Severe
10. *"Fullness of the Head" .... None .... Slight .... Moderate .... Severe
11. Blurred Vision .... None .... Slight .... Moderate .... Severe
12. Dizziness with Eyes Open .... None .... Slight .... Moderate .... Severe
13. Dizziness with Eyes Closed ...... None .... Slight .... Moderate .... Severe
14. **Vertigo .... None .... Slight .... Moderate .... Severe
15. ***Stomach Awareness .... None .... Slight .... Moderate .... Severe
16. Burping..................................... None .... Slight .... Moderate .... Severe
17. Vomiting................................... None .... Slight .... Moderate……...Severe
18. Other _________________ ..... None .... Slight .... Moderate……...Severe

* Fullness of the head is an awareness of pressure in the head.

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

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

10.10 Appendix J – Realism Survey

Study: _V2VSA_
Participant: ________
Date: ________

REALISM QUESTIONIRE

For each of the following items, circle the number that best indicates how closely the simulator resembles an actual car in terms of appearance, sound, and response. If an item is not applicable, circle NA.

	General Driving	Not at all Realistic						Completely Realistic	
1	Response of the seat adjustment levers	0	1	2	3	4	5	6	NA
2	Response of the mirror adjustment levers	0	1	2	3	4	5	6	NA
3	Response of the door locks and handles	0	1	2	3	4	5	6	NA
4	Response of the fans	0	1	2	3	4	5	6	NA
5	Response of the gear shift	0	1	2	3	4	5	6	NA
6	Response of the brake pedal	0	1	2	3	4	5	6	NA
7	Response of accelerator pedal	0	1	2	3	4	5	6	NA
8	Response of the speedometer	0	1	2	3	4	5	6	NA
9	Response of the steering wheel while driving straight	0	1	2	3	4	5	6	NA
10	Response of the steering wheel while driving on curves	0	1	2	3	4	5	6	NA
11	Feel when accelerating	0	1	2	3	4	5	6	NA
12	Feel when braking	0	1	2	3	4	5	6	NA
13	Ability to read road and warning signs	0	1	2	3	4	5	6	NA
14	Appearance of car interior	0	1	2	3	4	5	6	NA
15	Appearance of signs	0	1	2	3	4	5	6	NA
16	Appearance of roads and road markings	0	1	2	3	4	5	6	NA
17	Appearance of rural scenery	0	1	2	3	4	5	6	NA
18	Appearance of intersections	0	1	2	3	4	5	6	NA
19	Appearance of other vehicles	0	1	2	3	4	5	6	NA
20	Appearance of rear-view mirror image	0	1	2	3	4	5	6	NA
21	Sound of the car	0	1	2	3	4	5	6	NA
22	Sound of other vehicles	0	1	2	3	4	5	6	NA
23	Overall feel of the car when driving	0	1	2	3	4	5	6	NA
24	Overall similarity to real driving	0	1	2	3	4	5	6	NA
25	Overall Appearance of driving scenes	0	1	2	3	4	5	6	NA

1

Study: V2VSA
Participant: __________
Date: __________

	Situational Driving	Not at all Realistic					Completely Realistic	
26	Feel of driving straight while going 25 mph	0	1	2	3	4	5	6	NA
27	Feel of driving straight while going 55 mph	0	1	2	3	4	5	6	NA
28	Feel of driving on a curved road while going 25 mph	0	1	2	3	4	5	6	NA
29	Feel of driving on a curved road while going 55 mph	0	1	2	3	4	5	6	NA
30	Feel of accelerating from a stopped position	0	1	2	3	4	5	6	NA
31	Feel of braking to a stop	0	1	2	3	4	5	6	NA
32	Ability to stop the vehicle	0	1	2	3	4	5	6	NA
33	Ability to respond to other vehicles	0	1	2	3	4	5	6	NA
34	Ability to keep straight in your lane	0	1	2	3	4	5	6	NA
35	Ability to respond at intersections	0	1	2	3	4	5	6	NA

2

10.11 Appendix K – FCW Debriefing Statement

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 drives, because doing so may have impacted your actions and thus skewed the study results.

In this study, we were interested in understanding your reactions to a forward collision warning. You were told that we were studying differences among drivers across the US; however, in reality, a forward collision was simulated while you were distracted and data about your reaction to the warning modality was collected. Although, it is true that people in several locations across the US are participating in this study.

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 January 1st, 2015.

10.12 Appendix L – ICW Debriefing Statement

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 drive, because doing so may have impacted your actions and thus skewed the study results.

In this study, we were interested in understanding your reactions to an intersection collision warning. You were told that we were studying differences among drivers across the US; however, in reality, an intersection collision was simulated and data about your reaction to the warning modality was collected. Although, it is true that people in several locations across the US are participating in this study. One of the warning modalities was that no alert was given, so it is possible you did not experience an alert.

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 31, 2015.

DOT HS 812 511
December 2018

U.S. Department
of Transportation

National Highway
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